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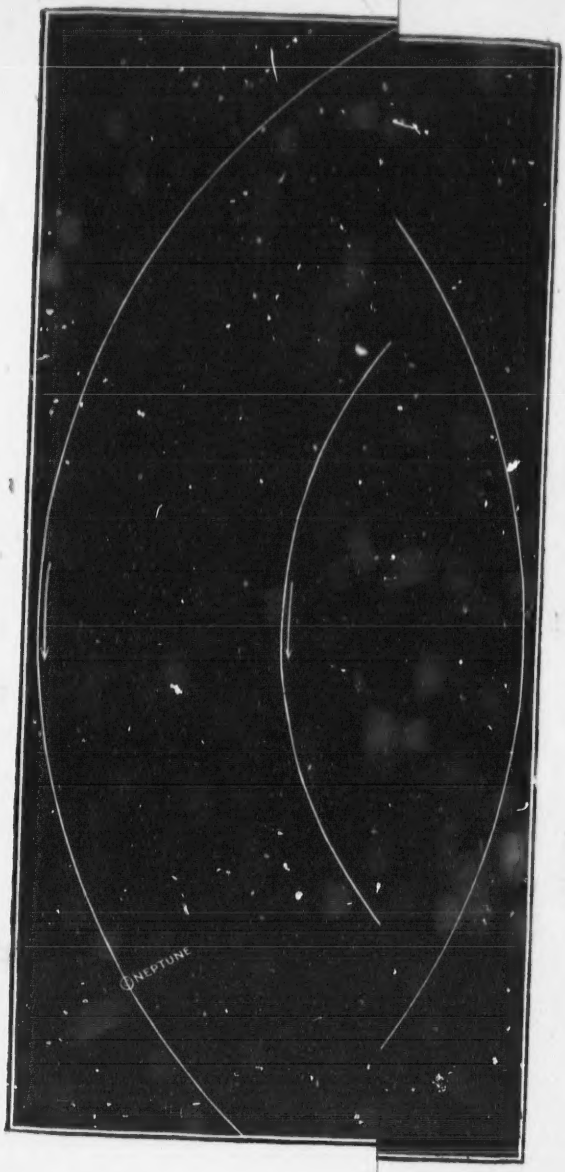
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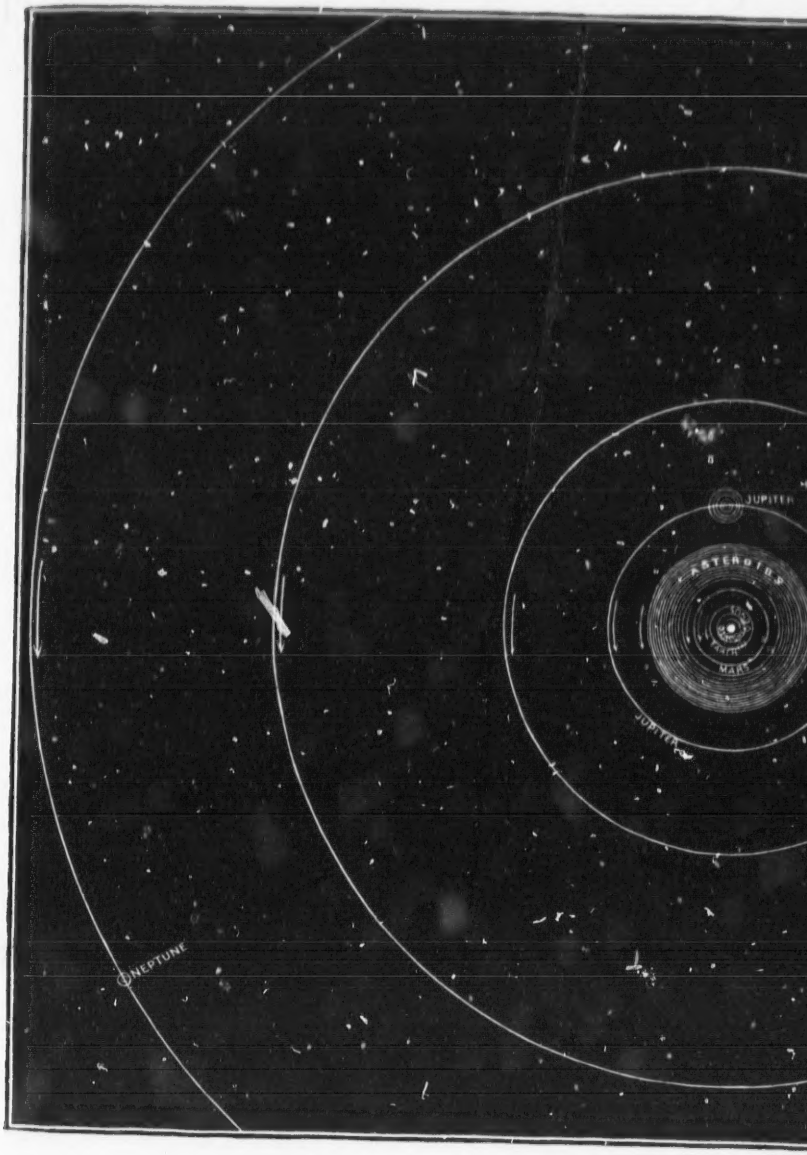

PLAN OF THE SOLAR

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PREFACE TO THE FOURTH EDITION.

Among the many able hand-books of physical science that have recently appeared, very few can be compared with the work now re-issued, either in naturalness of plan, terseness of style, or accuracy of description.

Since the publication, however, of the third edition, extraordinary progress has been made in every department of Astronomy, and discoveries effected vying in importance with the brilliant achievements of Newton, La Place, and the elder Herschel. In particular, the great physical problem of the age—*the earth's mean distance from the sun*—has been well-nigh definitely and satisfactorily solved. Equally important have been the splendid discoveries resulting from the researches of Kirchhoff and others in spectrum analysis; inasmuch as they lay open to us, for the first time, the physical constitution of the great central orb of our system, and conclusively demonstrate that the sun, stars, earth, and all the other members of the planetary system, are mainly composed of the same identical materials; and they also throw special light on the peculiar condition of the nebulæ.

Great additions have been made to our knowledge of the individual members of our system. The existence of a planet, nearer the sun than Mercury, has been all but demonstrated. The planet Mars, at the form of whose orbit the illustrious Kepler laboured for so many years—labours resulting in the three famous "laws of motion" for which that astronomer will be for ever distinguished—is now clearly shown to be enveloped in an atmosphere; to have his surface variegated with continents, oceans, islands, and seas; and, in fact, to contain the chief requisites essential to animal and vegetable life. The same researches, however, have also shown the great improbability of Mars sharing these characteristics with any other orb of the solar system; unless, indeed, we are to except the inner satellites of Jupiter, Saturn, and the other larger

planets, which, so far as our present knowledge extends, may perhaps be homes of living beings. Jupiter and Saturn themselves can no longer be regarded as habitable worlds, notwithstanding the eloquent pleadings of Sir David Brewster; but rather as *expiring suns*, no longer, indeed, shining with all their wonted light, but still capable of yielding important supplies of heat to the tiny orbs that revolve more immediately around them.

Since the publication of the last edition, moreover, we have made the acquaintance of many additional members of the great family of asteroids, or smaller planets, which fill up the void between Mars and Jupiter. The mysterious colossal rings of Saturn have at length been shown to consist of myriads of small opaque bodies, each moving independently, and in its own orbit, around the planet, but forming collectively a series of luminous streams, which, in all probability, have their analogues in those streams of meteors and falling stars through which our planet passes in October and November of each year. These, and many more of the results of recent astronomical research, are embodied in this new edition. At page 179 will be found elaborate tables, prepared by Professor C. Piazzi Smyth, Astronomer-Royal for Scotland, showing in detail all the more important facts hitherto established by astronomers relative to the sun, moon, and planets.

In preparing this new edition, the Editor has freely availed himself of the various admirable expositions of Astronomy by Richard A. Proctor, B.A., including "The Sun—Ruler, Fire, Light, and Life of the Planetary System," "Other Worlds than Ours," "The Orbs Around Us," etc.; also of J. N. Lockyer's exquisite little volume, entitled "Elementary Astronomy;" of G. F. Chambers's "Descriptive Astronomy," Oxford, 1867; "Popular Astronomy," by Sir George B. Airy, Astronomer-Royal; and of the new edition of the late Sir John Herschel's "Outlines of Astronomy," Longmans, 1871. A plan of the solar system, and a good index, have also been added; and, altogether, it is hoped the work will be found to be abreast of the present state of astronomical science.

ALEX. MACKAY.

EDINBURGH, *January* 1874.

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ELEMENTS

OF

ASTRONOMY.

Introduction.

1. **Astronomy** is the science which treats of the heavenly bodies.

2. By the "heavenly bodies," we mean the Sun, the Moon, the Earth, and the Stars.

3. The discoveries of astronomy have taught us to class the world which we inhabit among the heavenly bodies, having proved many resemblances between them. We now know that our earth is a *star*, although it does not appear to *us* to be one; and that several of the stars are large, solid, opaque bodies like the earth under our feet.

4. The ancients would not admit any community of nature between the earth and the stars. This idea of the essentially opposite nature of the earth and the brilliant luminaries which shine in the sky, for a long time retarded the progress of astronomy.

5. Astronomy informs us of what is known regarding the *forms* of the heavenly bodies, their *magnitudes*, *distances*, *relative situations*, *apparent motions*, *real motions*, *physical constitution*, and *actions on each other*.

6. The term Astronomy is derived from the Greek

words Αστηρ (aster), a *star*, and Νομος (nomos), *a law*. Its literal signification is, therefore, the law of the stars, or order of the stars.

7. A knowledge of astronomy is to be acquired partly by the study of books, partly by *observing the appearances of the heavenly bodies and the changes going on amongst them*. As the latter is very interesting in itself, as well as essential to a full understanding of the phenomena of astronomy, and as it can easily be pursued from the beginning, this work will open with a description of the *sphere of the heavens*.

PART I.

THE SPHERE OF THE HEAVENS.

1. Definitions.

8. **A Circle** is a curved line, every point of which is equidistant from a point within it, called the **Centre**. Considered with respect to the enclosed surface, which it bounds, it is often called the **Circumference**.

9. A **Sphere** is a round body (or a round space), every point on the surface (or outside) of which is equidistant from a point within called the **Centre**.

10. A **Diameter** of a circle, or of a sphere, is a straight line from any point in the circumference of the circle, or on the surface of the sphere, passing through the centre to the opposite side. A **Radius** is that half of a diameter between the centre and the circumference of the circle, or surface of the sphere; or, a straight line from the centre to the circumference of the circle or surface of the sphere.

11. The **Horizon** or **Sensible Horizon** of a place is that circle all round where the earth and sky appear to meet. We cannot see the earth beyond it, nor the sky below it. It bounds or limits our view; and takes its name from a Greek word having this signification.

12. The **Zenith** is the part of the sky right above

the head of the observer: and it means the same whether we say that a heavenly body is *in the zenith at any place*, or, that *it is vertical at that place.*

13. **Rotation** is the act of a body turning round on itself, without moving out of its place; as when a top sleeps in spinning. The body is then said to rotate. The term is derived from the Latin verb *roto*, I whirl, or turn round in a circle, probably from the noun *rota*, a wheel.

14. When a body rotates, there is an imaginary straight line in it which keeps the same place—every other part describing a circle round some point in that line. This line is called the **Axis**, or **Axis of Rotation.**

15. A body may have a motion of *translation*, that is, be continually changing its place, at the same time that it has one of rotation; as the wheel of a carriage in motion, or a ball rolling along the ground. But each motion may be considered separately.

16. **Apparent Motion** is the apparent change of a body's position, arising from a change in the position of the observer, not from a real motion of the body. It is sometimes called *relative motion.*

17. **Real Motion** is when a body actually does change its position. It is sometimes called *absolute motion.*

18. A person moving along a road in a carriage has real or absolute motion: while the change of position which he observes in the trees, houses, etc., is only an apparent or relative motion of these objects.

19. Motion is called **Uniform**, when its rate remains the same, that is, when the moving body passes over equal spaces in equal times; **Accelerated**, when the rate of motion is continually increasing; **Retarded**, when the rate is continually diminishing.

2. Apparent Motion of the Heavens—North Pole.

20. When we turn our eyes towards the sky, it appears to us to be the concave or inner surface of a hollow sphere in the centre of which we are placed. It is convenient to regard it as such, and to imagine various lines drawn upon it, to enable us to define with precision the positions of the heavenly bodies. This hollow sphere we shall call "the heavens."

21. The heavens appear to be in continual motion *from east to west* around us, carrying the sun, moon, and stars along with them: for, if we observe the position of any heavenly body, in respect to the earth, at any time, and look for it again in an hour or two, we shall find it to the west of its former position.

22. Also, we shall find that there is a movement of the whole heavens, not merely of one body, as the sun, or any bright star we may watch; for, 1. We find the westward movement in every one whose course we watch, and, 2. The different celestial objects preserve the same positions in relation to each other, showing that they all move together. Some ancient astronomers, who believed that this was a real motion of the heavens, were perplexed how to explain the various bodies preserving the same relative positions in this great westerly movement, and imagined that they were all immovably connected to each other by being embedded, like jewels when set, in a *crystal sphere*, which performed the revolution, and carried sun, moon, and stars along with it.

23. The heavens are found to make one complete revolution in 24 hours (correctly, 23 hours, 56 minutes, 4·09 seconds). This is known by noting carefully the position of a star in reference to any fixed terrestrial object, and observing the time that elapses before it again comes into the same position.

24. But this is only an *apparent* motion: the real motion which causes it, is the rotation of the earth from *west to east* in the same time. This is proved by a variety of reasons, which will be alluded to subsequently; but two things may be stated at present, which will satisfy us that the apparent revolution of the sky *may* be caused by a real motion of the earth. 1. *We may be in motion without perceiving it*, as in the cabin of a ship, or of a canal boat, or in a railway train, moving gently, when we may be carried a considerable way without knowing that we have moved at all. We do not perceive motion when it is uniform, so that there are no jarrings or joltings, and when the bodies around us are moving at the same rate, so that we retain the same relative position to them. 2. *We know also that our motion may cause bodies to appear to move which are really standing still;* as, when we are in a rapidly moving train, the trees, hedges, and banks appear to flit quickly past us in a direction opposite to that in which we ourselves are moving.

25. When the motions of the stars are observed, they all seem to move together from the east side of the horizon towards the west. Some rise very far south, ascend but a little way above the horizon, and set far south on the west side of the horizon: some rise in the east, ascend very high in the sky, and after describing a large curve in the heavens, set in the west: others rise and set north of due east and west: others do not set at all, but describe complete circles above the horizon round one point: others describe smaller and smaller circles round that point; and the stars very near that point appear, to judge by the naked eye, *not to move at all.*

26. That point is the **North Pole of the Heavens.** There is a similar point opposite to it in the southern region of the sky, which is hid from the view of those who live north of the equator, and which is the centre

round which the southern stars appear to move daily. These two points are the extremities of the imaginary line or axis, about which the heavens appear to rotate daily. They are vertical at the poles of the earth, and in the horizon at its equator.

27. At any place on the earth's surface, the pole of the heavens, visible there, always appears in the same position in relation to fixed objects at that place, while every other point in the sky is continually changing its position in relation to them.

28. The poles of the heavens may also be defined as the points where the earth's axis produced would meet the sky.

29. There is a pretty bright star very near the north pole of the heavens, called the **North Polar Star**, which may be easily found out.

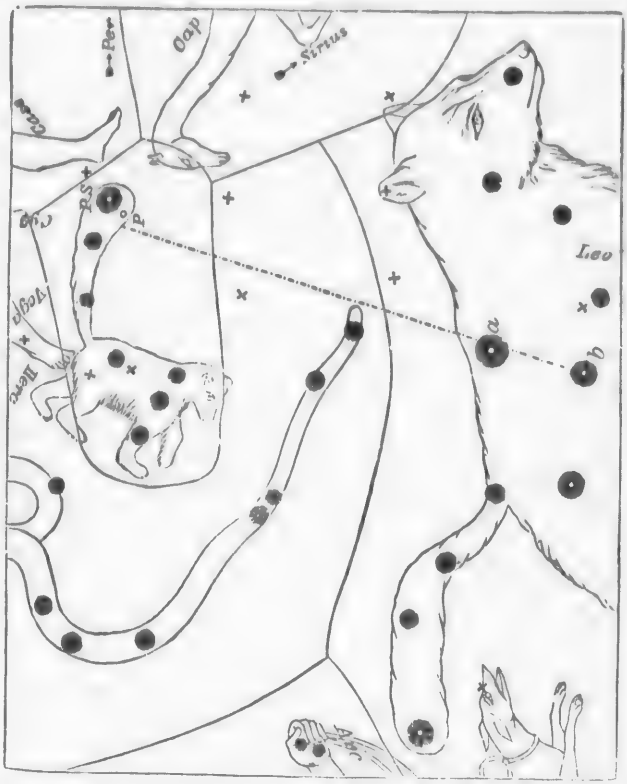
30. The ancients had the starry heavens mapped out into constellations, each consisting of a collection of adjoining stars, separated from the others by an imaginary line, and included under one name, expressive of some figure which the leading stars in the constellation were supposed to resemble.

31. The stars in each constellation are named by the letters of the Greek alphabet,—the brightest being termed α (alpha); the next brightest β (beta), and so on. When there are more stars in a constellation than there are Greek letters, the others are denoted by numbers. The leading stars in each constellation have usually some name applied to each, as Dubhe, Capella, Vega, Arcturus, Aldebaran.

32. At the left side of Fig. 1, may be observed a cluster of stars disposed within the figure of a small bear, and separated by a line from the adjoining stars. The stars within that line form a constellation, termed **Ursa Minor**, or the Little Bear. In the same figure are seen parts of other constellations—the **Great Bear** (Ursa Major), the **Dragon** (Draco), the hand of **Boötes**, and the feet of **Cepheus**.

33. The north pole-star is the brightest star in the constellation Little Bear, at the tip of its tail. It is marked P S in the figure. It is easily found out by means of the well-known seven bright stars commonly

Fig. 1.



called *the Bear*, *the Plough*, *Charles's Wain*, *the Butcher's Cleaver*. These stars are represented in Fig. 1, towards the lower part of the right side. If, when these stars are in any position, a straight line be imagined through

the two (*b* and *a*) farthest from the tail, and produced in a direction *from* the limbs of the animal, that line will pass close to the north polar star. These two stars are hence called "the Pointers."—The small circle ° marked P, near the pole-star, shows the true position of the north pole of the heavens.

34. These seven stars do not set in Great Britain. At one time they are seen between the pole-star and the horizon; at other times, higher in the sky, east or west of the pole-star; at other times, over head, nearly in the zenith.

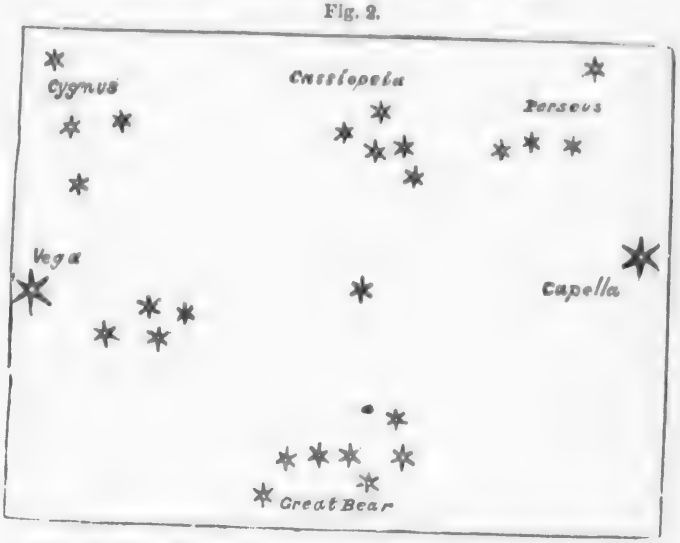
35. If the direction of north be known, the pole-star may easily be found. Looking north, in Britain, it will be seen a little higher than half-way between the horizon and the zenith.—The height of the pole above the horizon is always the same number of degrees, etc., as the latitude of the place; and as Britain extends from about 50° to 60° N. lat., the North Polar Star will in that country be from 50° to 60° above the horizon—according to the latitude of the place.

36. The first thing to be done, in studying the heavens, is to know the **North Polar Star**, which may be readily found out by the methods described. Having found it, let some convenient fixed station be taken, such that when at that station the polar star appears in the same straight line with the eye and some prominent object, as the top of a steeple, or tree, or the corner of a house. We shall then find, that at all times of the night, and at all times of the year, that star will always be in the very same position in relation to our station and the object, and that every other heavenly body will appear to describe a daily circle round it. Those that are near it will describe small circles near it, and, unless by very close observation, will not appear to have moved at all; while each will describe a greater circle the farther it is from the polar star; and the motion of those at a considerable distance

from it will be so great, that we may observe them to change their position in relation to any fixed object on the earth (we remaining still in the same place) in the course of five or ten minutes.

37. The pole-star and constellation Great Bear being known, the next thing to be done is to look for the stars of the constellation **Cassiopeia**, and the very bright stars **Capella** and **Vega**. These stars never sink below the horizon in Britain, so that they may almost always be seen on clear nights; and they are very distinct and prominent, so that by their aid the other heavenly bodies can easily be found out. See Fig. 2.

Fig. 2.



38. A line drawn from about the middle of the tail of the Great Bear through the pole-star, and continued nearly as far on the other side of that star, will terminate in the constellation **Cassiopeia**, or Lady in her Chair. The prominent stars in this constellation are five in number, and arranged so as to make a figure

somewhat like the letter W, but straggling, and with one limb of the W shorter than the other. Cassiopeia is one of the constellations in that broad whitish belt extending across the sky, called "**The Milky Way.**"

39. A straight line from the pole-star, perpendicular to the line joining the pointers and pole-star, and on the same side of that line as the head of the Bear, passes close to a very bright star called **Capella,** a little farther from the pole-star than the pointers. This is the brightest and most northern of the stars in the constellation **Auriga,** or Charioteer.

40. On the other side of the pole-star from Capella, but still farther from the pole, may be seen a very bright star called **Vega,** the principal star in the constellation **Lyra.**

41. These five—the Great Bear, the Pole-star, Cassiopeia, Capella, and Vega—are almost always visible in Great Britain, and the student of astronomy should, as soon as possible, make himself acquainted with their appearance and relative positions, as well as with their daily changes of position in relation to him. They are represented in the preceding sketch, with one or two others that are prominent in that part of the heavens around the north polar star.

42. The student will do well also to observe carefully the following celestial phenomena, and make himself practically acquainted with the various details connected with them.

43. The changes of the moon; its daily motion completely round the heavens; the [illegible] direction of its daily motion through the sky; the stars near which it passes in its course; the position it occupies in respect to the sun at different times; the form of the edge turned towards the sun, etc.

44. With respect to the sun, he should observe the different points of the horizon at which it rises at different times, the differences in the elevation it reaches at

the various seasons of the year; and he should take particular notice of the stars near the sun, which he will discover by observing those visible near where the sun has just set, or where he is about to rise. By the latter observations, he will soon find that the sun travels through the stars, and completely round the sky in one year; and that the course it takes through the sky is nearly the same as that which the moon takes in her monthly circuit. These interesting facts were known to the ancient astronomers long before man's power of vision was augmented by the telescope.

45. In this remarkable part of the sky, through which the sun and moon pursue their course unceasingly, he will occasionally find bright stars which do not, like most of the stars, always retain the same relative positions to each other, but which move about amongst them. These are the **Planets.** They do not twinkle as the other stars do; and they change their positions in the sky, always however remaining near that circle or belt of the heavens through which the sun and moon run their courses. There are five planets visible to the naked eye, Mercury, Venus, Mars, Jupiter, and Saturn. The first of these, however, can be seen but seldom, being very near the sun, amid the brilliancy of whose rays Mercury's faint light is usually lost to our view.

46. These phenomena, which have been just alluded to, along with those of climate and seasons, the length of the day, trade-winds, tides, and eclipses, are the chief objects of astronomical investigation, and present materials for observation and study open to every one. They embrace the grandest parts of the scenery of nature; and a knowledge of the movements going on in the heavenly bodies, of their general nature, of the varieties of them, and phenomena which they present, impart great additional interest to the view we enjoy of the heavens on a starry night—perhaps the most magnificent object in creation.

3. General Definitions.*

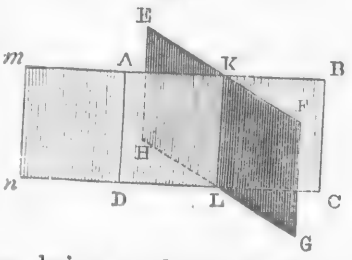
47. **A plane superficies, plane surface**, or, as it is shortly expressed, **a plane**, is a surface of such a nature, that if a straight line be drawn between any two points in it, every point in the straight line shall touch the surface.

48. A plane, in common language, is called a *flat* surface. A wall, a well-smoothed table, a mirror, in whatever position it may be held, furnish examples of a plane surface. Its nature will be at once understood by endeavouring to apply the above definition to any curved surface, as a sphere: the straight line between two points will pass below the curved surface.

49. When two plane surfaces, on being produced so as to meet, would form one plane, *they are said to be in the same plane.*

In Fig. 3, the planes *m* A D *n*, K B C L, are in the same plane, as, on being produced, they form one plane, *m* B C *n*.

Fig. 3.

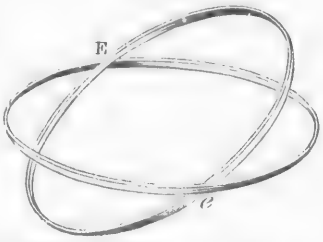


50. Two tables, of the same height above the floor, and perfectly horizontal, are in the same plane.

51. When two planes, on being produced so as to meet, would cross each other, and then diverge, they are said *to be inclined to each other*, or, *to cut each other.*

In Fig. 3, the planes E K L H, A K L D, are inclined to each other. The two planes in Fig. 4 are also inclined to each other. See also Fig. 5, in which a number of planes are shown inclined to each other.

Fig. 4.

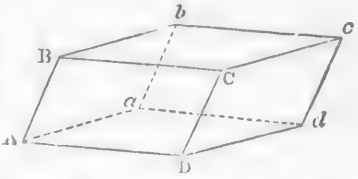


52. Planes which are

* These definitions may appear numerous and tedious; but there is no possibility of any one *understanding* even the limited extent of astronomy given in this little volume without a thorough comprehension of the meaning of the terms now to be explained.

everywhere at the same distance, are said to be *parallel.* In Fig. 5, the planes B *b c* C, A *a d* D, are parallel; also the planes B *b a* A, C *c d* D. The opposite walls of a room are parallel, also the floor and ceiling.

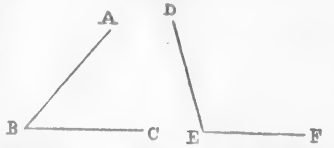
Fig. 5.



53. If two planes cut each other, the line where they meet is a straight line; as K L, Fig. 3, E *e*, Fig. 4, or any of the straight lines in Fig. 5.

54. We speak of the plane of any figure, though the interior of it be not filled up, if it be one every point of which would touch a plane surface when laid upon it; as a triangle, a square, a circle, an ellipse. Such a figure is termed **a plane figure.** Thus, we speak of the plane of the path of a planet, meaning the imaginary plane surface which would touch every point of the planet's course: and we may imagine it to be extended on any side far beyond the actual path of the planet. It is essential for the student of astronomy to understand what is meant by "the plane of a figure."

Fig. 6.

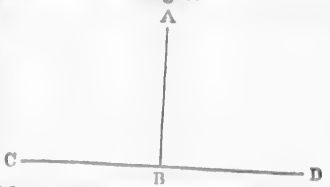


55. An **Angle** is the opening between two straight lines, which meet, but are not in the same straight line. In Fig. 6, the opening between the lines A B and C B is an angle, termed the angle B, or the angle A B C: the letter at the point where the lines meet is placed in the middle.

56. A **Right Angle** is the angle formed when one straight line stands upon another in such a manner that the angles on each side are equal to one another. These angles are termed the *adjacent angles.* In Fig. 7, A B C and A B D are right angles, for they are equal to each other.

57. The line which stands upon the other is termed a **Perpendicular,** and is said to be *perpendicular* or *at right angles* to the other. In Fig. 7, A B is perpendicular to C D:—also D B and C B are, each of them, perpendicular to A B.

Fig. 7.



58. A straight line is said to be perpendicular to a plane, when it is perpendicular to every straight line drawn on that plane which it meets.

59. An **Obtuse Angle** is one which is greater, or has a wider opening, than a right angle. In Fig. 6, D E F is an obtuse angle. An **Acute Angle** is one which is less, or has a narrower opening, than a right angle. In Fig. 6, A B C is an acute angle.

60. The method of comparing angles exactly, with respect to their magnitude, is described in Par. 75, page 22.

61. The **Inclination of a Straight Line to a Plane** is the smallest angle which the line makes with any straight lines drawn on the plane.

62. The **Inclination of a Plane to a Plane** is the acute angle contained by two straight lines, one in each plane, drawn from any point in the straight line in which the planes cut each other, at right angles to that line.

63. Two lines which are everywhere at the same distance, are said to be **Parallel** to each other, or **Parallel Lines.**

64. Planes or lines which are parallel to the plane of the horizon, are called **Horizontal**; as the surface of a liquid when still, or floors and ceilings properly constructed.

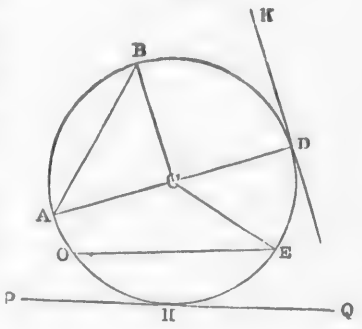
65. Any straight line or plane that is perpendicular to the plane of the horizon, is said to be **Vertical**; as a plumb-line (a cord with a weight at its end freely suspended), or the walls of buildings.

66. When the sun is right over head at any place,

his rays fall upon it so as to be perpendicular to the plane of its horizon; that is, *vertically*. He is then said to be vertical at that place.

67. A **Circle** has been already defined in Par. 8. In Fig. 8, C is the centre, and the curved line A B D E H O, the circumference of the circle; C A is a radius; C B and C D are also radii. A D is a diameter.

Fig. 8.



68. It follows from the definition of a circle (8.) that all radii of the same circle are equal in length.

69. The diameter is double the radius, and it divides the circle into two equal parts.

70. An **Arc** of a circle is any portion of the circumference. In Fig. 8, D E, E H, H O, B E, E O, are arcs of the circle A B H O.

71. A **Semicircle** is the part cut off by the diameter, or half the area of the circle. In Fig. 8, A B D A and A H D A are semicircles. A **Quadrant** is the half of a semicircle. In Fig. 8, A B C A and D B C D are quadrants.

72. The terms *semicircle* and *quadrant* are sometimes applied to the portions of the circumference which bound them, as well as to the area enclosed. In this case, the semicircle is *one-half*, the quadrant *one-fourth* of the circumference.

73. The magnitude of an arc of a circle is described by stating what proportion of the whole circumference it forms. For this purpose, the circumference of a circle, whatever its magnitude may be, is supposed to be divided into 360 equal parts, called *degrees*, and marked °. To express still smaller parts, each degree is divided into 60 equal parts, called *minutes*, and marked ′; and each minute is subdivided into 60 equal

parts, termed *seconds*, and marked ″. Thus, an arc of thirty-nine degrees, forty minutes, and thirty-one seconds, is shortly expressed, 39° 40′ 31″.

74. A semicircle is an arc of 180 degrees; a quadrant an arc of 90 degrees.

75. **An Angle is measured** by making its sides radii of a circle, the angular point being the centre, and taking the length of the arc on which it stands, in degrees, minutes, and seconds. The arc on which the angle stands is the portion of the circumference between the extremities of its sides or radii. In Fig. 8, the angles A C E and D C E are measured by the number of degrees in the respective arcs A H E and D E, on which they stand,—the angle A C E by the arc A H E, the angle D C E by the arc D E. We thus speak of an angle, as of so many degrees and minutes in magnitude. The angle B C D, whose arc B D is a quadrant or fourth-part of the circumference, is therefore an angle of 90 degrees. The angle D C E must be considerably less, about 60 degrees or 60°—the angle A C E, about 120°. The arc on which an angle stands is said to *subtend* that angle.

76. An angle of 90° is a right angle: an acute angle is less than 90°; an obtuse angle greater than 90°.

77. The length of the radii, or magnitude of the circle, makes no difference in the size of the angle, for the arc on which the same angle stands will always bear the same proportion to the whole circumference, however different that circumference may be, or whatever the length of the radius.

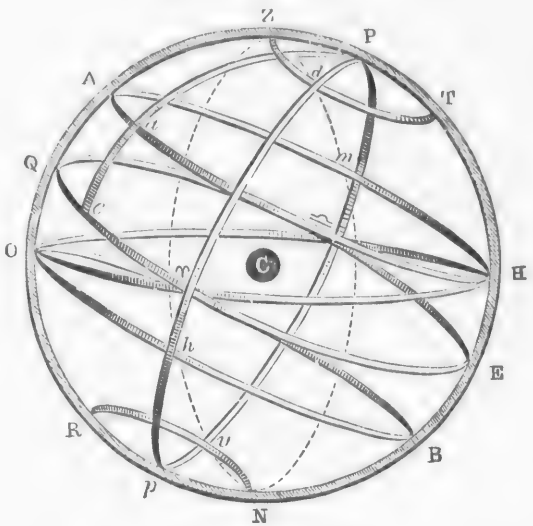
78. The sphere has been defined in Par. 9. The adjoining figure will illustrate the nature of those lines which are imagined in or on a sphere with the view of defining the relations of the different parts. In Fig. 9, straight lines from E to Q, from P to *p*, and from Z to N, would be diameters.

79. **A Great Circle** of a sphere is a circle drawn upon its surface, whose plane passes through the centre

of the sphere. In Fig. 9, P ♈ *p* *v*, the dotted line, Z *h* *v* N *m*, E ♈ H ♎ O ♈, and the outer circle, are great circles.

80. All great circles of a sphere are equal to each other; cross each other twice, divide each other into two equal semicircles, and divide the surface of the sphere into two equal parts called **Hemispheres.** In Fig. 9, each of the great circles P ♈ *p*, Q *e* ♈ E,

Fig. 9.



divide each other into two equal parts or semicircles, the former into ♈ P ♎ and ♎ *p* ♈, the latter into ♎ Q ♈ and ♈ E ♎.

81. A **Small Circle** of a sphere is a circle drawn upon its surface, whose plane does not cut the centre of the sphere. In Fig. 9, Z *d* T, A *a* H, N *v* R, are

* This character, ♈, may be read, Aries—this mark, ♎, Libra.

small circles. Or, a small circle of a sphere divides its surface into two unequal parts.

82. Distances on a sphere, and the breadth or length of figures on its surface, are expressed in degrees of some of the circles drawn on its surface.

83. When a sphere revolves, like a top spinning, this is termed *rotation on its axis.* The **Axis** about which it rotates is usually a diameter: and the extremities of the axis are termed **Poles** of the sphere.

84. The extremities of a diameter at right angles to the plane of a great circle are sometimes termed the **Poles** of that great circle. In Fig. 9, P, *p* are the poles of the great circle E ♈ *e* Q; Z, N, the poles of the great circle H ♈ O ♎.

85. The poles of a great circle are each of them 90° distant from that circle. That is, if a great circle be drawn through the poles of any great circle, cutting the latter, the part of the former between each pole and the second great circle will be 90°, or 1-4th of the whole circumference. In Fig. 9, the arcs P *a e*, P *d* ♈, between the great circle E ♈ Q and its pole P, are arcs of 90° each.

86. It is impossible to represent a sphere accurately on a flat surface. In Fig. 9, the outer circle is the only one which retains its proper form—the others appear as *ovals.* But each of these should represent a true circle (8).

4. How to define the Positions of Objects in the Heavens.

87. It is necessary, for astronomical purposes, to be able to define the exact position of the stars in the heavens. This is done by taking certain fixed points or lines, and marking the distance of each star from these points or lines.

88. For this purpose, the surface of the heavens is

regarded, as it appears to us, as a concave sphere, and an infinite number of lines, crossing each other, are supposed to be drawn upon it. These lines are divided into degrees, numbered from certain fixed points; and by observing the position of a star on these lines, where two of them cross each other, its situation can be determined with great precision. This is illustrated by the following figure (10).

89. Two points are taken in the sphere of the heavens (one is close to the north pole-star) at the opposite extremities of the axis of rotation of the heavens. These are represented by N and S in Fig. 10. The first, N, is termed the **Northern Pole of the Heavens**; the second, S, the **Southern Pole of the Heavens.** These are the primary fixed points. They are the poles of the heavens, as described in Par. 26.

90. An infinite series of great circles is supposed to be drawn on the sphere, all passing through the two poles. These are represented in Fig. 10 by N *e* S, N *d* S, N *c* S, N *r* S; only one-half of each circle being seen in the figure. These are termed **Hour-Circles** or *celestial meridians.* The whole of the outer one, N E S Q, is seen.

91. A great circle round the heavens at equal distances from each pole, is termed **The Equinoctial.** It is 90° from each pole, and is represented by the line E Q in Fig. 10. It receives its name from *æquus*, equal, and *nox*, night; because when the sun is on that line, there is equal day and night all over the world. This is on March 20 and September 23.

92. The equinoctial is the line which the plane of the earth's equator would make round the sky, if we imagine that plane produced so as to cut the sky.

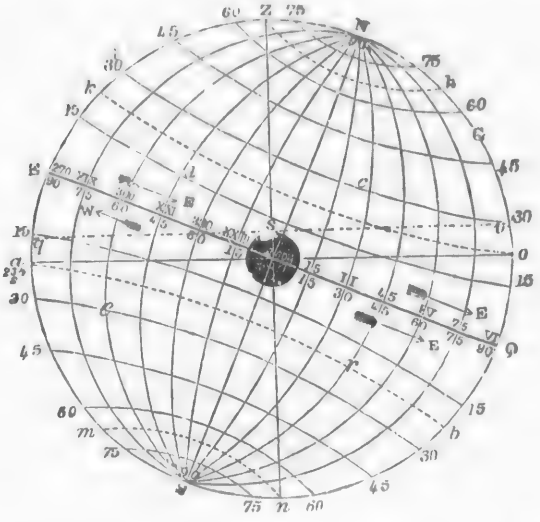
93. Numbers of small circles are supposed to be drawn north and south of the equinoctial, and parallel to it, lying between it and each pole. These are re-

presented in Fig. 10, by Z *h*, *k o*, etc., north of the equinoctial, and *q* 15, *a b*, *m n*, etc., south of the equinoctial. These circles are termed **Parallels of Declination.**

94. All these circles are supposed to be divided into degrees, minutes, and seconds, as described in Par. 73.

95. In any hour-circle there will be arcs of 90 degrees between the points where it crosses the equinoctial and either pole, and these arcs will be crossed by every parallel on the same side of the equinoctial.

Fig. 10.



Accordingly, each *parallel* is named by its distance north or south from the equinoctial, measured by the number of degrees along an hour-circle which it is distant from the equinoctial. Thus, from E by Z to N is 90° of the hour-circle N E S Q. The first parallel shown north of E Q crosses N E S Q at 15° from E Q; that parallel (15 *d* 15) is therefore 15° north; its dis-

tance north of E Q is termed its **North Declination**; and every point in that parallel, as *d*, being at the same distance from E Q, has the same **Declination**.

96. The point *c* is in *north declination* 30°, the point *e* in *south declination* 30°. See also Fig. 9, page 23, in which P *p* are the poles; E ♈ Q, the equinoctial; Z *d* T, A *a* H, O *h* B, parallels; P *a e*, P ♈ *p*, hour-circles. In that figure, the arc *e a* is the north declination of *a*; the arc ♈ *d*, the north declination of *d*; E B, the south declination of B.

97. The equinoctial circle is divided into 360 degrees, etc., which are numbered from the point where the sun crosses it in spring, which is called the first point of the sign **Aries**; or the **Vernal** or **Spring Equinox**. (See Par. 104.) It is at 360, in the middle of the line E Q in Fig. 10. It is marked by the sign ♈. —See Fig. 9. Every hour-circle crosses the equinoctial, and each is named according to the degree, minute, etc., where it cuts the equinoctial. The distance of an hour-circle east from the vernal equinox is termed its **Right Ascension**. T is, the hour-circle N *r* S, Fig. 10, crossing the equinoctial at 45° east from the equinox, any point in that half (N *r* S) is said to be in *right ascension* 45°.

98. Thus, by knowing the parallel of declination and hour-circle in which a star is situated, we know its precise position, as every parallel crosses every hour-circle.

99. In Fig. 9, page 23, if P and *p* represent the poles of the heavens, and E ♈ *e* Q the *equinoctial*, the number of degrees from *e* to *a* will be the declination north of the point *a*, and its right ascension will be the degrees from ♈ round by E, ♎, and Q, to *e*, ♈ being the vernal equinox, or point in the equinoctial from which the degrees are reckoned. In Fig. 10, the point *c* is in right ascension 30°, *north declination* 30°: the point *d* in *right ascension* 315°, north declination 15°; and so on.

100. R. A. is the contraction used for right ascension; D. N. declination north; D. S. declination south.

101. The distances from the vernal equinox are sometimes reckoned in *hours*, each hour consisting of 15 degrees, and being divided into 60 minutes. In Fig. 10, *above the line* E Q, the degrees are marked alternately in hours and degrees; thus, commencing at the equinox, we have first 15°, next II hours (30°), then 45°, then IV hours (60°), 75°, VI hours (90°), etc. To bring time to degrees, we must multiply by 15. Thus, $10^{h.}\ 3^{m.} = 150°\ 45'$.

102. The degrees of right ascension are reckoned *eastward* from the equinox, all the way round from 0° to 360°: that is, in the direction **from the head towards the tail of the Great Bear**, *when that constellation is between the pole-star and the horizon.*

103. The places of the sun and planets are expressed in the almanacs by stating their right ascension and declination.

104. Observations of the sun have shown that he appears to move round a great circle of the heavens in a year. This great circle is called the **Ecliptic**; as eclipses take place only when the moon also is upon that line. The ecliptic is represented by the line *a o* in Fig. 10, and S P in Figs. 11 and 12. The points where it crosses the equinoctial are called the equinoctial points or *equinoxes;* the first point of Aries, ♈, where they cross in spring; the first point of Libra, ♎, where they cross in autumn.

105. The plane of the ecliptic makes an angle of $23\frac{1}{2}°$ with the plane of the equinoctial; so that the farthest north point of the ecliptic is only $66\frac{1}{2}°$, while the farthest south point is $113\frac{1}{2}°$ ($90° + 23\frac{1}{2}°$) from the north pole of the heavens.

106. The sun is in the north or highest point of the ecliptic on June 21, and he is then vertical at the tropic of Cancer:—he is in the south or lowest point on December 21, and is then vertical at the tropic of Capricorn. When he crosses the equinoctial

(March 20 and September 23) he is vertical at the equator.

107. The north part of the ecliptic, where the sun is in June, is in that part of the heavens a little south of a bright star called **Capella**, which lies to the west of the Great Bear, but at a greater distance from the north pole. See Fig. 12.

108. As there are 360 degrees, and one revolution of the sphere is completed in 24 hours, each point in the heavens must move 15 degrees *west* in one hour. The same relation prevails as to time and degrees of longitude on earth—each point moves 15 degrees *east* in one hour.

109. The ecliptic is divided into 12 equal parts, of 30° each, called **Signs**, and numbered from the first point of **Aries**, which is the first of these signs. A belt of the heavens, extending a few degrees on each side of the ecliptic, is called the **Zodiac**, from the constellations there being mostly figures of animals (from the Greek *zodion*, the figure of an animal). Hence, these signs are often called **Signs of the Zodiac**.

110. The table on next page exhibits the signs of the zodiac, with the time of the sun entering into each, the characters used for each, and one or two other particulars.

111. As the sun enters the sign Cancer on the 21st of June, the parallel on the earth at which he is then vertical is called the tropic of **Cancer**, and as he then retraces his course, that parallel (either on the earth or the heavens) is called a **Tropic** (from the Greek *trepo*, I turn). The tropic of **Capricorn** receives its name for similar reasons.

112. As the sun appears to pause or stand still a day or two before turning, the time is termed **Solstice** (*sol*, the sun, *sto*, I stand)—December 22, the winter solstice; June 21, the summer solstice.

Northern Signs. Ascending.	Aries, the Ram,	♈,	March	*20.	Spring Equinox (day and night equal everywhere).
	Taurus, the Bull,	♉,	April	20.	
	Gemini, the Twins,	♊,	May	21.	
Northern Signs. Descending.	Cancer, the Crab,	♋,	June	21.	Summer Solstice (midsummer in the northern hemisphere).
	Leo, the Lion,	♌,	July	22.	
	Virgo, the Virgin,	♍,	August	22.	
Southern Signs. Descending.	Libra, the Balance,	♎,	September	22.	Autumnal Equinox (day and night equal everywhere).
	Scorpio, the Scorpion,	♏,	October	23.	
	Sagittarius, the Archer,	♐,	November	22.	
Southern Signs. Ascending.	Capricornus, the Goat,	♑,	December	22.	Winter Solstice (midsummer in the southern hemisphere).
	Aquarius, the Waterman,	♒,	January	20.	
	Pisces, the Fishes,	♓,	February	19.	

* These dates vary a little in different years.

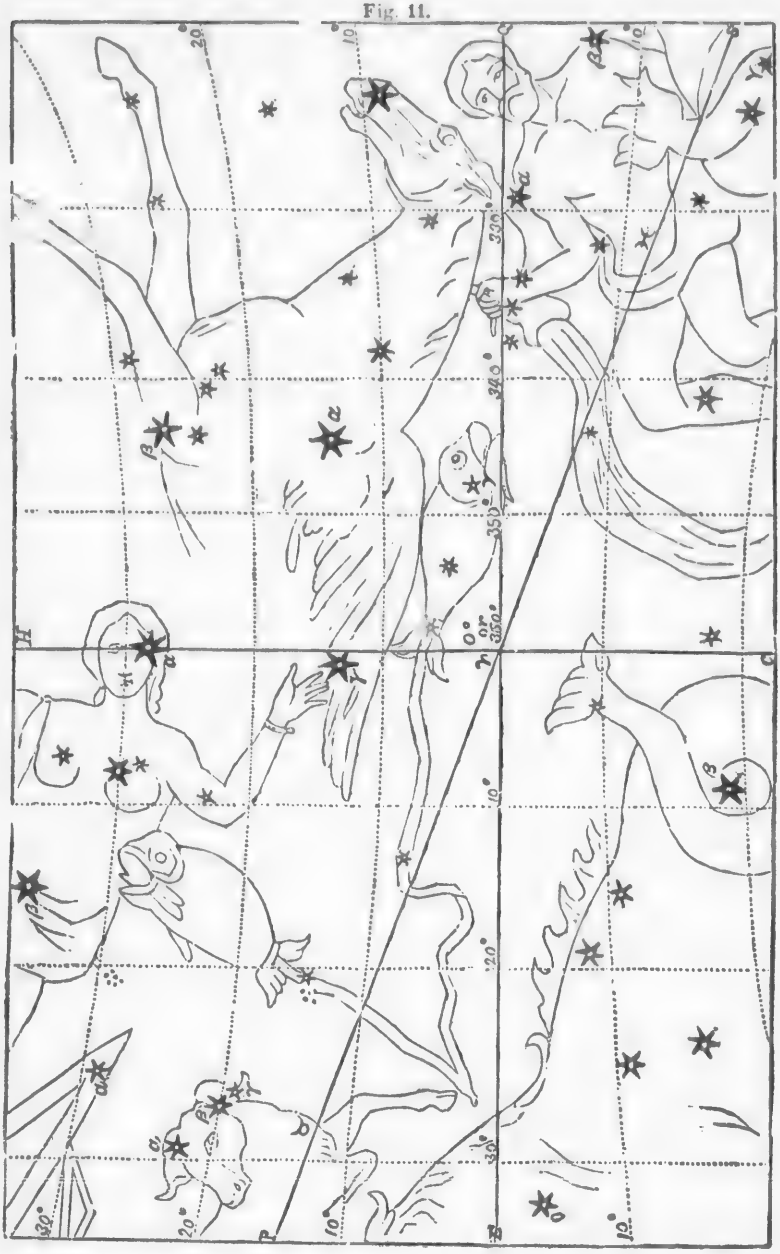
113. The signs of the zodiac in which the sun appears when he is north of the equinoctial, are called the *northern signs;* those in which he is when south of the equinoctial, *southern signs;* those in which he is passing in a northerly direction are called *ascending;* those in which he is going south, *descending*.

114. The terms longitude and latitude are also employed for the heavens—but with reference to the *ecliptic* and its poles (85). Thus, the *latitude* of a celestial body is its distance north or south from the ecliptic; its *longitude* is its distance east of the half-circle from the north to the south pole of the ecliptic passing through the first point of Aries. The north pole of the ecliptic is in the constellation Draco, $23\frac{1}{2}°$ from the north pole of the heavens, and in R. A. 270°. The north pole of the heavens moves so as to describe a circle round the pole of the ecliptic in 25,898 years. The movement thus made is too slight to be apparent in a lifetime; but in time the north pole will be far removed from the present pole-star, and will return to it again at the end of the above-mentioned period.

115. From this motion (which will be explained afterwards—see "Precession of the Equinoxes," par. 667) the equinoctial points move backwards upon the ecliptic; and the signs of the zodiac, which were originally named from constellations in these signs, do not now correspond with these constellations.

116. The following figure (11) represents the constellations around the first point of Aries, and the leading imaginary lines in that region. The line E Q is part of the equinoctial; S P represents the sun's yearly path through the heavens, usually called the ecliptic, the sun moving in the direction shown by the order of the letters, from S towards P. The point where these two great circles cross in that quarter of the heavens, where the sun is on March 20, is the first point of Aries. The hour-circle passing through that point is the first hour-circle, from which degrees of right ascension are reckoned. It is marked H C in the figure; and the degrees are seen marked on the equinoctial, increasing eastward from that hour-circle, or towards the left in the figure. The dotted lines are parts of parallels of declination and hour-circles. It

Fig. 11.



will be observed that *eastward* is towards the *right* in Figs. 9 and 10, but towards the *left* in Figs. 11 and 12. In the latter, we see the stars as they appear to us who view them from the *interior* of the starry heavens; but in Figs. 9 and 10, as on globes and maps, we view the objects from the *outside* of the sphere on which they are placed.

117. The student is here strongly recommended to make himself acquainted with the right ascension and declination of several leading stars, so that he knows thoroughly and can trace out for himself, on viewing the heavens, the position of the principal hour-circles and parallels. He will then find it very easy to discover the following stars and constellations; as well as any other star or planet whose R. A. and Dec. he knows.

118. The following are several of the principal stars and constellations, with instructions by which they may be easily found out by the learner. The constellations are arranged in three divisions, northern, southern, and zodiacal constellations. The zodiacal canstellations occupy the belt of the heavens a few degress on each side of the ecliptic. The northern constellations are those on the same side of the zodiac as the north pole; those on the southern side of the zodiac are the southern constellations.

5. Northern Constellations.

119. The **Great Bear** (*Ursa Major*) is well known. Its seven brightest stars are in the body and tail of the figure. The greater part of this constellation is shown in Fig. 1. Its brightest star, one of the pointers, marked *α* in Fig. 1, and termed **Dubhe**, is in R. A. $10^{h.}\ 54^{m.}$, or about 163°; and D. N. 62° 32′. The star at the tip of the tail, called **Benetnasch**, is in R. A. $13^{h.}\ 41^{m.}$, or about 205°; D. N. 50° 7′.

120. Upon the other side of the Little Bear, but nearer to it, is an irregular cluster, which have been thrown into a male figure called **Cepheus**, the feet of which are seen in Fig. 1.

121. The constellation **Cassiopeia**, or Lady in her Chair, and the stars Capella and Vega, have been already

described. **Capella** is in R. A. $5^{h.}$ $5^{m.}$, or about 76°; D. N. 45° 50′. This is the brightest and most northern of the leading stars in the constellation **Auriga**, or the Charioteer. The principal stars in this constellation, along with one of Taurus, form an elongated six-sided figure, stretching from north to south, and very well marked. See Fig. 12. Capella does not set in Great Britain.

122. Between Capella and Cassiopeia, but further south, is the constellation **Perseus**. Three of its leading stars form a gentle curve. It is shown in Fig. 2, par. 37. The star above the letters *us* in Perseus, is **Algol**, a remarkable star, to be described afterwards.

123. A straight line from the pole-star, in the direction nearly opposite to the line cutting Capella, leads to another very bright star, **Vega**, the principal star in the constellation **Lyra**. Vega is in R. A. $18^{h.}$ $31^{m.}$, or about 277°; and D. N. 38° 38′. This star does not set north of London, just skirting the horizon.

124. East of Vega, in R. A. from $20^{h.}$ to $21^{h.}$, and D. N. about 33° to 45°, are seen four bright stars, three nearly in a line, and one above the middle of the three: these are the principal stars in the constellation **Cygnus**, or *Swan*, which lies in the Milky Way. They are shown in Fig. 2.

125. A straight line from the pole-star, passing near the star in the tip of the tail of the Great Bear, and twice the distance of the tail from the pole-star, cuts **Arcturus**, a very bright star, of a distinct reddish colour, the principal star in the constellation **Boötes**, or the *Huntsman*. Arcturus is in R. A. $14^{h.}$ $8^{m.}$, or about 212°; and D. N. 19° 56′.

126. A straight line south from Cassiopeia, and nearly at right angles to the line joining Cassiopeia and the Swan, will pass near a large square of four stars; the furthest north and brightest of which is is **Alpherat**, the principal star in the constellation

Andromeda; while the other three of the square are part of the constellation **Pegasus**. The star Alpherat is in R. A. $0^{h.}$ $0^{m.}$ $47^{s.}$, about 0°, that is, on the hour-circle crossing the equinox; D. N. 28° 16′. It is on the eye of Andromeda, which constellation stretches eastward across the heavens towards Perseus, from Alpherat.

127. This prominent square, with several other principal stars near it, are represented in Fig. 11. The constellations Aquarius, Pisces, and Aries of the zodiac are seen extending along the ecliptic, S P. At the south-east (left) are seen several stars of the great constellation **Cetus**. In a line with the two most westerly stars of the square, α and β of Pegasus, but far south, the bright star **Fomalhaut** may be seen. It is in R. A. 342° 15′; D. S. 30° 23′.

128. In ancient times, when names were given to the signs and constellations, the ecliptic and equinoctial crossed each other about 30° further east than now—that is, nearly where the sign of Taurus (♉) is seen on the ecleptic in the figure. Then the 30° east of that point were in the constellation Aries, and these 30 were from their position termed the *sign Aries*. But now the equinoctial has receded back or west along the ecliptic, and the old names for both signs and constellations being retained, they do not correspond. The sign Aries is in the constellation Pisces; the sign Pisces in the constellation Aquarius, and so on.

129. The brightest star in the constellation Cassiopeia has nearly the same R. A. as Alpherat; or rather between $0^{h.}$ and $1^{h.}$ eastward. Between Arcturus and Vega, but considerably nearer Arcturus, is a half-circle of stars, termed **Corona Borealis**.

130. South-east of **Corona** lies the great constellation **Hercules**. There are four stars forming a sort of diamond or lozenge in Fig. 2, near Vega. The three nearest to the pole-star belong to the constellation

Draco, the stars in which form a curve between the Great and Little Bears, and between the latter and Hercules. The other is in the foot of **Hercules**.

6. Zodiacal Constellations.

131. These are twelve in number, and encircle the heavens like a belt. They are named **Aries**, the Ram; **Taurus**, the Bull; **Gemini**, the Twins; **Cancer**, the Crab; **Leo**, the Lion; **Virgo**, the Virgin; **Libra**, the Balance; **Scorpio**, the Scorpion; **Sagittarius**, the Archer; **Capricornus**, the Goat; **Aquarius**, the Waterman; **Pisces**, the Fishes. The constellations of the zodiac do not rise high above nor sink far below the horizon in Great Britain.

132. The sun, moon, and principal planets, are always found in some of the constellations of the zodiac.

133. The brightest star in **Aries** is in R. A. $1^{h.}\ 58^{m.}$, about 29°, D. N. 22° 45′. See Fig. 11.

134. **Aldebaran**, the brightest star in **Taurus**, is in R. A. $4^{h.}\ 27^{m.}$, about 67°; and D. N. 16° 12′. The **Pleiades**, or seven stars of Taurus, are in R. A. about 54° 30′, and D. N. 23° 38′. See Fig. 12.

135. **Castor** and **Pollux**, the brightest stars in **Gemini**, are very near each other; Castor, in R. A. $7^{h.}\ 25^{m.}$, or about 111°; and D. N. 32° 12′; Pollux, in R. A. $7^{h.}\ 36^{m.}$, or about 114°; and D. N. 28° 22′. See Fig 12.

136. There are no very prominent stars in the constellation **Cancer**.

137. **Regulus**, the principal star in **Leo**, is on the ecliptic in R. A. $10^{h.}$, about 150°; D. N. 12° 41′. The leading stars in this constellation form a figure like a sickle, of which Regulus is the handle. This great constellation is nearly due south of the Great Bear.

138. **Spica**, the brightest star in **Virgo**, is in R. A. $13^{h.}\ 17^{m.}$, or about 199°; and D. S. (declination south) 10° 23′. It is a very little south of the ecliptic.

139. The constellations **Libra, Scorpio, Sagittarius,** are seldom seen in Great Britain.

7. Southern Constellations.

140. The only southern constellations of interest that are frequently visible in Great Britain are, **Orion, Canis Minor,** and **Canis Major**: these constellations lie due south of **Capella** and **Gemini,** and are very prominent in the heavens during our winter.

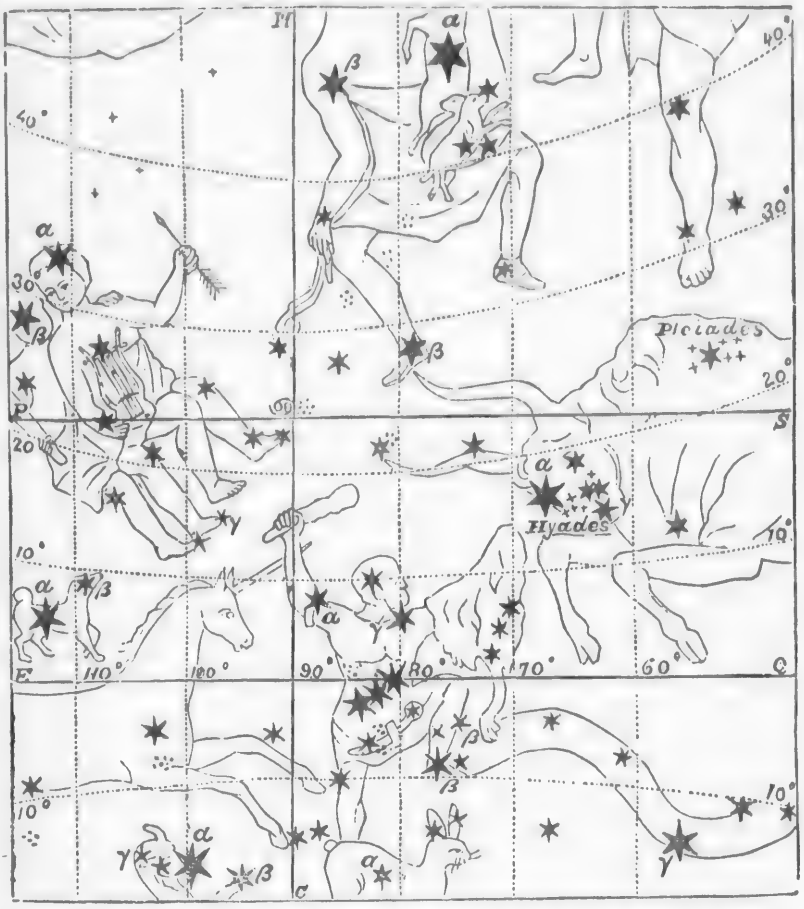
141. **Orion** is a large well-marked figure, a little east of due south from Capella. It is in the form of a four-sided figure, considerably elongated from north to south. In the middle are three stars, lying in a south-east and north-west direction, usually termed **Orion's Belt. Betelgeux,** the brightest star in Orion, is in the north-east angle. It is of a distinct reddish colour. It is in R. A. $5^{h.}\ 47^{m.}$, about 88°; in D. N. 7° 22′.

142. **Sirius,** in the constellation **Canis Major,** the Greater Dog, and the brightest of the fixed stars, is south-east from Orion, in R. A. $6^{h.}\ 38^{m.}$, about 100°; and D. S. 16° 31′.

143. **Procyon,** a star of the first magnitude, in the constellation **Canis Minor,** or Lesser Dog, is nearly due south from the Twins, and due east of Betelgeux. Its R. A. is $7^{h.}\ 31^{m.}$, about 113°; its D. N. 5° 35′.

144. These stars and constellations are represented in the following figure (12). At the upper part or north is seen the constellation **Auriga** or Charioteer with the bright star **Capella,** also shown in Fig. 2. At the east, we observe **Gemini, Orion** below, **Taurus** at the right, with the clusters, **Pleiades** in the shoulder, and **Hyades** in the head. At the south-east is seen the very bright star **Sirius,** α of the constellation **Canis Major**; and north-east of Sirius, **Procyon,** α of the Lesser Dog, and another prominent star β near it. At the left toe of **Castor,** the more northern of the Twins, is the first point

Fig. 12.



of the sign **Cancer**, where the sun is on June 21, being his greatest distance north from the equinoctial. This is the summer **Solstice**.

145. It will be observed that Sirius, Orion's Belt, the Hyades with Aldebaran (α), and Pleiades, are

nearly in one line; and that Orion is nearly due south of Capella. The limbs at the north-west corner of the figure are those of Perseus, the leading stars in whose body are shown in Fig. 2. Below Orion is seen the constellation **Lepus** or Hare, and at the right the great constellation **Eridanus.** Between Dec. S. 56° and 62°, and R. A. 180° and 190°, there is a brilliant constellation, well known in southern latitudes as the **Southern Cross,** once (about 4000 years since) visible in the south of Britain, now lost to our view by *Precession.*

146. The **Milky Way,** another prominent object in the heavens, lies between **Procyon** and **Sirius,** passes north-west between Gemini and Orion, then through Auriga, south-west of Capella; then passes through several minor constellations and Cassiopeia, and south-west, splitting into two divisions, south of the constellation **Cygnus** or the Swan, not far from Vega.

8. Extent of the Heavens visible at any Place.

147. With respect to the extent of the heavens visible at any place, the celestial sphere may be divided into three portions:—1. That part which never sets at the place (*i.e.*, never sinks below the horizon), and the stars in which are always visible on clear nights. 2. That part which is only occasionably visible, being sometimes above, sometimes below, the horizon of the place. 3. That part which is always below the horizon of the place, and therefore can never be seen from that place.

148. The **Celestial Meridian** of any place on earth means the **Hour-circle** which passes through the zenith of the place. The distance from the zenith to the horizon along that circle will be 90°.

149. At any place, the height of the pole of the heavens above the horizon (called the *elevation of the pole*) is always the same number of degrees, minutes,

etc., as the latitude of the place. That is, if we measure the number of degrees, etc., along the celestial meridian of a place from the horizon to the pole, there will be exactly as many as in the latitude of the place. The N. latitude of London is 51° 30′, and there the north pole (or north polar star, which is close to the pole) is 51° 30′ above the horizon. At Edinburgh, the elevation of the pole is 55° 57′, for that city is in N. L. 55° 57′.

150. The distance in degrees, etc., of the zenith of a place from the equinoctial is the same as the elevation of the pole, or latitude of the place.

151. The distance of the zenith from the pole (called *the zenith distance of the pole*) is equal to the difference between the elevation of the pole and 90°; at London, 38° 30′; at Edinburgh, 34° 3′. And this is equal also to the elevation of the equinoctial above the horizon on one side, or its depression below the horizon on the other side of the heavens.

152. Thus, at London, the terrestrial latitude, elevation of the pole, and zenith distance of the equinoctial, are each 51° 30′. The zenith distance of the pole, elevation of the equinoctial above the horizon, and its depression below the horizon, are each 38° 30′.

153. That part of the heavens between the pole and a parallel of declination the same distance from the pole as its elevation at the place, *never sets*. Thus, at London, the stars 51° 30′ all round from the north pole can always be seen on a clear night. A parallel 51° 30′ from the pole is 38° 30′ from the equinoctial, that is, about 38° D. N. If we look for that parallel on a map of the stars, we shall find north of it all the stars which may be seen at London.—Or, it may be said, that the stars at a less distance from the pole than the degrees in the latitude of the place, or than the north point of the horizon, never set.

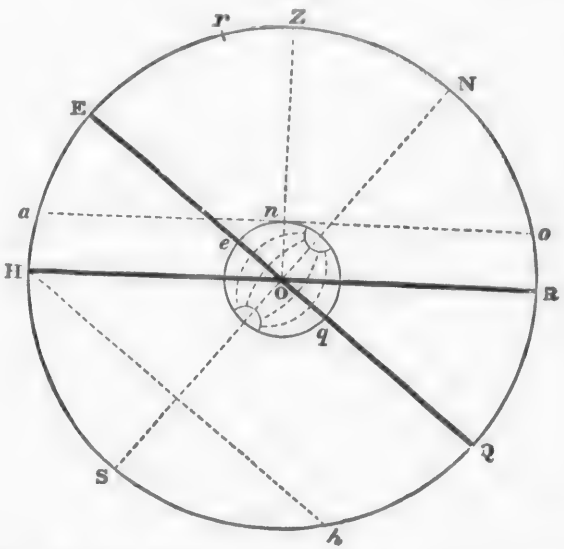
154. A like part of the heavens around the opposite

pole *never rises*. Thus, at London, the stars 51° 30′ all round from the south pole are never seen : or all those beyond 38° 30′ D. S.

155. The part of the sky forming the intermediate belt is sometimes above, sometimes below the horizon of the place. That belt extends as many degrees on each side of the equinoctial as are in the elevation of that line above the horizon. Thus, at London, the stars in the belt of sky from 38° 30′ D. N. to 38° 30′ D. S. (a breadth of 77° +), are sometimes above, sometimes below the horizon.

156. This will be understood from the following figure :—

Fig. 13



157. Let the small circle in the middle represent the earth, *n* an observer on its surface, about the latitude of London or Edinburgh ; the great outer circle, his celestial meridian ; then Z will be his zenith. Let

N be the north pole of the heavens, S the south pole, and let E Q represent the plane of the equinoctial; the part where it crosses the earth (*e q*) will represent the earth's equator. From E to N will be 90°, and from Q to N also 90°. From S to E and to Q will be the same number of degrees, making 360° all round.

158. The dotted line *a o* will be the *sensible horizon* of the observer at *n*; the points *a* and *o* being the parts of the sky below which he could not see the heavens for the earth interposing. Let H O R be a plane parallel to that of the sensible horizon, but passing through the centre of the earth. It is plain that, if the inner circle representing the earth were smaller, the place of the observer, *n*, and also the line *a o*, would be proportionably nearer to H O R; and that if the space in the figure occupied by the earth were reduced to a mere point, the lines (or planes) *a o* and H O R would coalesce. Now this is actually the case with respect to the horizon of any place on the earth and the starry heavens. The distance from the earth's surface to its centre is as nothing—a mere point—in relation to the distances of the stars; and hence, in relation to *them* there is no practical difference between the *sensible horizon a o*, and a plane parallel to it passing through the earth's centre, which is called the **Rational Horizon,** and represented by the line H O R in the figure. We may therefore reason with respect to the starry heavens and the positions of the earth in relation to them, as if the observer at *n* were at the earth's centre O, and the distances *a* H, *o* R in the sky, and *n* O reduced to nothing.

159. H and R being the points where the horizon meets the sky, the distances from Z to H and to R, will be 90° each.

160. From Z to R being 90°, and from E to N 90°, taking away the arc Z N, which is a part of each, there will remain the arc N R, the elevation of the pole,

equal to the arc Z E, the zenith distance of the equinoctial; which it is manifest is the same number of degrees in the celestial meridian as *n e* on the terrestrial meridian, *which is the latitude of n.*

161. Since H Z, E N, and N Q are 90° each, by taking E Z from each of the first two, and the equal arc N R from the last, there remain E H, the elevation of the equinoctial above the horizon, Z N, the zenith distance of the pole, and R Q, the depression of the equinoctial below the horizon, all equal to each other, and equal to the difference between the elevation of the pole and 90°.

162. Now, in considering the apparent daily rotation of the sphere of the heavens, so far as relates to the remote fixed stars, we may regard the observer at *n* as if he were at O, and his horizon H O R as shutting out from his view all below the line H O R. Also, the points N and S, the poles of the heavens, maintain the same places. Hence, in rotating, all the stars from N by *o*, R, Q, and *h*, to S, will in 12 hours have come to like distances from N and S on the other side of these points, along the line N Z E *a* H S; and stars on the latter line will be on the opposite line from N by Q to Z.

163. A star at *r* (the same distance from N as R) will in 12 hours be at R, just on the horizon; stars at R will have been elevated to *r;* and all north of these points will have continued above the horizon during the whole rotation; that is, *always* to the observer at the place *n*.

164. The stars from R by Q to *h* will in 12 hours come to the position *r* E H, any star at *h* just appearing upon the horizon at H; and the stars from *r* to H then sink below the horizon, as from R to *h*.

165. The stars, from *h* by S to H, in the rotation of the celestial sphere, evidently cannot rise above the horizon at all. They are never seen at the latitude of *n*.

166. It may easily be shown that the arcs S H, S *h*,

are each equal to E Z or N R; and that the arc Q *h* is equal to each of the arcs E H, Q R, or Z N.

167. Thus, at the latitude of *n*, the part of the heavens from *r* by N to R, never sets; the part from R to *h*, or *r* to H, is sometimes above, sometimes below the horizon; the part from H by S to *h*, is never above the horizon.

168. At London, **Vega** just skirts the horizon when at the lowest point of its daily course; and **Capella**, in the opposite quarter of the heavens, at its lowest point, is about 7° above the horizon; so that these two very bright stars are almost always visible in Great Britain, at about from 50° to 45° from the north polar star.

169. The motion of the earth round the sun, by which we undergo a change of place to the extent of no less than 184 millions of miles, makes no sensible difference in the relative positions of the earth and fixed stars. That enormous distance is but a mere point in comparison with the distance of the stars. At all times of the year, the pole of the heavens is in the same relative position to every place upon earth.

170. It will be observed, that though the stars in their daily rotations preserve the same relative positions at each place, they arrive at these positions at different times of the day; so that stars which are above the horizon during night at one season, are below the horizon during night, and cannot be seen at another season. This arises from the time of one complete daily rotation of the starry sphere being a little different from the time occupied by the sun in his apparent daily revolution round the earth, which is called a solar day, and by which the periods of night and day, and our divisions of time, are regulated.

171. Upon considering the relations of the various parts of the earth's surface to the starry sphere during the apparent daily rotation of the latter, it will be found that at the poles, only one and the same half of the starry heavens will be above the horizon during the 24

hours—that hemisphere north or south of the equinoctial; and that at the equator, the spectator will have above his horizon in the course of 24 hours the *whole of the sphere* of the heavens—the poles of the heavens being in his horizon. The whole of the stars are brought under his view within the night of 12 hours; one-half at the beginning of that period, while the opposite half will be above his horizon at the end of that time. There alone man may enjoy, during the night of 12 hours, the magnificent spectacle of the whole of the sphere of the heavens.

PART II.

LEADING PHENOMENA OF THE EARTH, SUN, AND MOON.

SECTION I.

1. Definitions.

172. **The Poles** are the extremities of the earth's axis (83).

173. **The Equator** is an imaginary great circle round the earth, equidistant from the poles.

174. **Parallels of Latitude** are small circles round the earth, parallel to the equator. A parallel is called *the parallel* of any place through which it passes. is the circle which each place describes by the earth's daily rotation.

175. **Meridian Circles** are great circles round the earth, passing through both poles. Each cuts the equator and every parallel twice, and divides each of them into two equal semicircles.

176. A **Meridian** is that half of a meridian circle between the poles. It is called the meridian of any place through which it passes. A meridian is so called from the Latin word *meridies*, midday; because it is midday at a place when the sun is on its meridian.

177. The sun is said to be *on the meridian* of a place when he is in the plane of its meridian above the horizon; that is, at the greatest elevation in the sky, which he reaches at that place at that time in his apparent daily motion.

178. The meridian continuous with or opposite to the meridian of a place, is called the *opposite, or inferior, or lower meridian* of that place. It is the other half of the meridian circle passing through the place.

179. Those who live on the same meridian have *midday* at the same moment, *midnight* at the same moment, and their time corresponds.

180. Thus, the earth is divided by imaginary lines in the same manner as the sky; but the names applied to them are different.

The following table shows the corresponding terms:—

Heavens.	Earth.
Poles.	Poles.
Equinoctial.	Equator.
Parallels of Declination.	Parallels of Latitude.
Hour-circles.	Meridian-circles.
Declination.	Latitude.
Right Ascension.	Longitude.
Hour-circle through first point of Aries.	Meridian of Greenwich.

181. The same figure will serve for illustration. Let Fig. 10, page 26, be now viewed as a representation of the earth. N and S will be the north and south poles; E Q the equator; all the lines from N to S meridians; the curved lines crossing them, parallel to the equator, as *a b*, *k o*, are parallels of latitude.

182. **Latitude** is the distance of a place north or south from the equator. It is measured in degrees, minutes, etc., along the meridian of the place—the line going north and south through the place—and is marked on the parallels at the sides of the map. In Fig. 10, the line *c* H is the N. latitude of C.

183. **Longitude** is the distance of a place east or west of some agreed-on meridian, as that of Greenwich for the British, of Paris for the French, etc. Longitude is measured in degrees, minutes, etc., along the parallel of the place—the line going due east and west from a place. It is marked on the meridians where they cross the equator, or at the top and bottom of the map. Thus, in Fig. 10, if the straight line N S represent the meridian of Greenwich, the point *r* is in 45° E. L. (east longitude), as found by tracing its meridian to the equator, *under* which, in that figure, longitude is marked. *e* is in 60° W. L.

184. This gives us longitude and latitude in degrees, but does not tell us the *distance*. To find the distance of a place north or south from the equator—or east or west from the first meridian, we must multiply the number of miles in a degree of latitude or longitude by the number of degrees. In a degree of latitude there are 69 miles and 78 yards; but as the parallels decrease from the equator to the poles, the degrees of longitude are different at every latitude, and we must know the length of the degree of longitude at different parallels, to be able to find the distance between places expressed in degrees of longitude. This is to be found in tables in most geographical works. At the equator, a degree of longitude is 69 miles, 278 yards: 64 miles at 23½° N. L.—43 miles at London—38½ miles at Edinburgh—28 miles at 66½° N. or S. latitude; while at the poles,

where all the meridians meet, the degree of longitude is reduced to nothing.

185. The earth is 7925 miles in diameter at the equator—the widest part—7899 miles from pole to pole. Hence, at the equator, it is nearly 4000 miles from the surface to the axis; while this distance diminishes towards the poles, where the axis comes to the surface. This must be borne in mind in considering the effects of rotation.

186 The *tropic of Cancer* is the parallel 23½° north of the equator. It is the furthest north parallel at which the sun is vertical (65-6).

187. The *tropic of Capricorn* is the furthest south parallel at which the sun is ever vertical, and is at 23½° S. latitude.

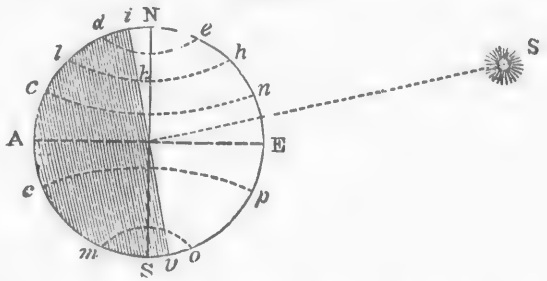
188. The part of the earth between the tropics is called the *torrid zone:* it is 47° in breadth, and is the only part of the earth's surface in which the sun is vertical. And the height of the sun at any place is less, as the place is further from this zone.

189. The parallel 23½° from the north pole, or 66½° N. lat., is called the *arctic* circle. The same parallel in respect to the south pole is called the *antarctic* circle. These are sometimes called the *polar circles.* See par. 207.

190. The parts of the earth's surface around the poles and within these circles, are called the *polar* or *frozen regions*, north and south.

191. The part of the earth's surface between the tropic of Cancer and the arctic circle is called the *north temperate zone.* The corresponding part in the southern hemisphere is the *south temperate zone.*

Fig 14.



192. In the preceding figure, if N and S be the north and south poles, and A E the equator, then *C n* will be the tropic of Cancer, *c p* the tropic of Capricorn, *d e* the arctic circle, and *m o*

the antarctic circle. The area *C n p c* will be the torrid zone—*d e n C*, the north temperate zone, and the part north of *d e* the north polar region, *c p o m* the south temperate region, and the part south of *m o* the southern frozen region.

SECTION II.

DAY AND NIGHT—CLIMATE—SEASONS.

1. Day and Night.

193. The constant and regular alternation of a period of light, termed **day**, and a period of darkness, called **night**, is caused by the earth's rotation on its axis.

194. The word *day*, as used in this section, signifies the period of light, that is, the period during which the sun is *above* the horizon of a place; *night*, the period when the sun is *below* the horizon of the place, and darkness prevails.

195. The change from night to day and day to night takes place in the following manner:—The sun enlightens only that half of the earth's surface which is turned towards him, while the other half is in darkness;—and as the earth, by its rotation on its axis, successively presents different parts of its surface to, and turns them from, the sun, these parts must have alternately light and darkness, or day and night.*

Proportions of Day and Night at Different Places.

196. We may be in five different states as to day and night. We may have equal day and night,—long day and short night,—no night,—short day and long night,—or, no day.

197. At the equator, the day and the night are of

* Not that every part of the earth's surface is turned towards the sun during *each rotation*; for this is not the case—but, during the year, every part of the earth's surface is at some period turned towards the sun.

equal length during the whole of the year, and there is a day and a night during each rotation of the earth on its axis, *i. e.*, in every 24 hours; the day and the night being 12 hours long each.

198. At the **Poles**, the day and the night are of equal length during the whole of the year;—but there is only *one day and one night* during the year, each being six months in duration (between March 20 and September 23). The dreary winter of the polar regions is relieved by reflected light or twilight, by auroras, and by the *full* moon, which shines upon those parts of the earth where the sun is below the horizon.

199. At other parts of the earth's surface the duration of day and night is different at different places, and at the same place at different times. The parts north of the equator (*northern hemisphere*) and those south of the equator (*southern hemisphere*) are always in exactly opposite conditions with respect to day and night. At corresponding latitudes, north and south (that is, at latitudes equally distant from the equator), the one's day is equal to the other's night—the one has *short day* and *long night*, when the other has *long day* and *short night*.

200. At two periods in each year, there is equal day and night over all the world;—and a day and a night during each rotation of the earth. These two times are termed **Equinoxes** (110). They are, March 20, the spring or *vernal equinox*, and September 23, the *autumnal equinox*.

201. From the equator to latitude 66° 32′ north, and to the same distance south—that is, in the torrid and temperate zones—the day and night are unequal at different places (excepting at the **Equinoxes**), and at the same place at different times:—and in this region there is always a day and a night during each rotation of the earth on its axis. These latitudes, it must be observed, are 23° 28′ distant from the poles.

202. From latitude 66° 32′, north and south, to each pole—that is, within the polar circles—the day or period of sunshine, during part of the year, *continues for several rotations of the earth on its axis;** the time the sun remains above the horizon varies from nothing to six months; the day is extremely long when there first comes to be a day and a night during each rotation; and the proportions gradually change till there is *continual night* during several rotations—and so on.

Manner in which these Differences occur.

203. The line between the dark part and the enlightened part of the earth's surface is called the **Terminator.** It may be called the *boundary line* between night and day. It forms a great circle (79), all round the globe, and divides the earth's surface into two equal hemispheres—one dark, where it is night; the other receiving the sun's rays, and having day. In Fig. 14, par. 191, the line *i v*, bordering the shaded part, is the terminator. The sun's rays are perpendicular to the plane of the terminator: as may be seen in the figure.

204. The terminator is on each spot of the earth which has both day and night at two periods during each rotation; first, when it is *sunrise*, and, again, when it is *sunset* at that place; and the sun is on the meridian of a place, or there is midday, when the place is equally distant on both sides from the terminator. The length of the day and of the night at different places depends upon the proportionate lengths of time which are spent on each side of the terminator.

205. The sun is always perpendicular to some part of the earth's surface, *i.e.*, is always in the zenith at some place; and the terminator will be 90° distant, all round, from the spot on which he is vertical at any time.

* That is, for several *days of* 24 *hours*, the sun never sets.

206. During one rotation of the earth on its axis (disregarding the earth's motion in its orbit during the time of one rotation), the parts successively brought round to be perpendicularly under the sun will be *those in the same parallel of latitude*. Thus, if in Fig. 15, page 53, A N E S be the earth, N S a meridian, S at the side the sun, and *n* the point at which the sun is vertical, the line *d o*, supposed to represent the terminator, will evidently be 90° distant from *n*. And as the axis, about which the earth turns, extends from N to S, the points that will be successively brought into the position of *n* by the rotation, will be those on the parallel C *n*; and the sun is then said to be vertical or perpendicular to that parallel: for, although he is perpendicular only to one point of it at a time, viz., where it is midday, he is during the whole rotation perpendicular to some part of it.

Long Day, etc., in the Northern Hemisphere.

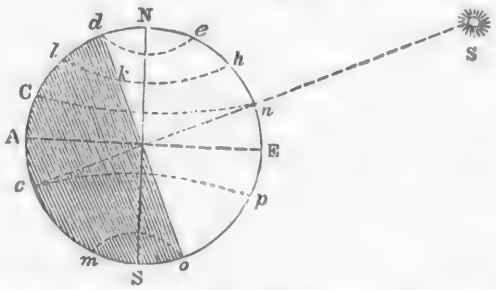
207. The sun on the 21st of June is vertical at the north tropic (tropic of Cancer), which is only 66° 32′ from the north pole; accordingly the terminator will then be 90° from that parallel, or 23° 28′ *beyond the north pole*; that is, reaching to the arctic circle. In fact, *the polar circles are the parallels at the greatest distances of the terminator from the poles*. In revolving, therefore, that pole and all within the arctic circle (the parts around it for a distance of 23° 28′* south) will have continual day; for they will never cross the terminator in their revolution. The sun will not set there, but describe a circle near the horizon varying slightly in its elevation. The parts further south, from lat. 66° 32′ to the equator, will describe *more than half of their daily circle on the enlightened side of the terminator*, and have longer day than night. And the proportion on

* 66° 32′ + 23° 28′ = 90°.

the illumined side of the terminator will diminish as the place is further south, till, at the equator, an equal portion of the time of rotation will be spent on each side of the terminator, and the day and the night will be equal.

208. This will be better understood by referring to the following figure, which illustrates the relation of the dark and illumined parts when the sun is on the tropic of Cancer. Let A N E S represent the earth, N the the north pole, S the south pole, N S a meridian; S, at the right, the sun, *d* A *o* the part of the earth not receiving the sun's light, *d o* the line of the terminator. Let *d e* be the arctic circle, 23° 28′ from the north pole; C *n*, the tropic of Cancer, 23° 28′ from the equator. It will be seen from the position of the sun that

Fig. 15.



the north pole is turned towards it, and the south pole from it. Any point, in revolving, will take twelve hours in passing from one side of N S to the other, as from *d* to *e*, or C to *n*, and twelve hours in returning again: and the middle of each twelve hours will be where the point crosses N S. Now, the earth revolving about a line from N to S, it will be at once evident that any point north of the dotted circle *d e* (the arctic circle), will never be out of the sun's rays, and therefore have constant day; that any point from *d e* to

A E the equator, will be more than half the period of rotation without the terminator; that it will be a less proportion of its course without the terminator, as it is further south from *d e;* that any point in A E will spend half its course within, and half without the terminator, as that circle cuts A E, the circle in which such a point revolves, exactly in the middle.

209. The point *l*, for instance, revolving in 12 hours from *l* to *h*, will have *h* for its midday or noon, when nearest to the sun; the point *k*, where the circle *l h* cuts the terminator, for sunrise; and *l* for midnight. As the period from sunrise to noon (from *k* to *h*) is longer than that from midnight to sunrise (*l* to *k*), so likewise the time from noon to sunset is longer than that from sunset to midnight:—and the whole day of that point will be longer than its night.

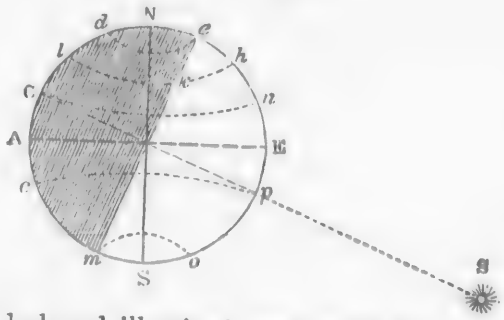
Short Day in the Northern Hemisphere.

210. On the 22d of December, the sun is perpendicular to the *south tropic* (tropic of Capricorn), which is 23° 28′ *south* of the equator, or 113° 28′ (23° 28′ + 90°) from the north pole. Accordingly, the sun will then be 90° from the arctic circle, and the terminator will be 23° 28′ *on this side of the north pole.* In revolving, therefore, that pole, and all within the arctic circle (the parts around it for a distance of 23° 28′ north), will have continual night, for they will never cross the terminator, but just skirt it in their revolution. The sun will not rise there. The parts further south, from 66° 32′ to the equator, will *describe more than half their daily circle on the dark side of the terminator*, and have longer night than day. And the proportion on the dark side of the terminator will diminish as the place is further south, till, at the equator, an equal portion of the time of rotation will be spent on each side of the terminator, and the day and the night will be equal.

211. The tropic of Capricorn, latitude 23° 28′ south, is the farthest south parallel at which the sun becomes vertical. At places farther south, he never reaches the zenith — never appears perpendicular — and appears lower as the place is farther south.

212. This will be better understood by reference to the adjoining figure; which illustrates the relation of

Fig. 16.



the dark and illumined parts when the sun is on the tropic of Capricorn. The same letters indicate the parts as in the former figure (page 53), excepting those at the terminator, which is now from *e* to *m*, completely enveloping in the shade the north pole and the regions around it for 23° 28′ south. Within the arctic circle there will be continual night. From that parallel to the equator A E, any point, in its daily rotation, will pass from midday to the terminator before it has gone through half of its circle, and will therefore have longer night than day. It will be enveloped in the dark half sooner after noon, and have longer night, in proportion as it is nearer to the pole. And as the terminator *e m* still cuts the equator in two equal parts, there will be equal day and night at the equator. Thus, the same point *l* is seen to reach the point *k*, where it meets the terminator, in more than six hours, and to be less than

six hours in revolving from *k* to *h*, its midday. From midday to sunset twill also be less than six hours; and its whole night must be greater than its day.

213. Thus, the northern hemisphere, with respect to the dark part of the earth's surface, is placed on December 22 (in Fig. 16) in exactly the same position formerly illustrated with respect to the illumined part.

State of the Southern Hemisphere.

214. As already mentioned, the two hemispheres are always in exactly opposite conditions in regard to day and night, except at the time of the equinoxes. This is at once seen by inspection of Figures 15 and 16. When the sun is on the north tropic (Fig. 15), and the north pole is entirely in the illumined part, the south pole is entirely in the shade. When the sun is on the south tropic (Fig. 16), the north pole is out of the reach of his rays, and the south pole is never out of them, etc. At the equinoxes, when the sun is vertical at the equator, and the terminator passes through both poles, each hemisphere is situated in the same position with respect to the sun's rays, and they are therefore in similar conditions as to day and night.

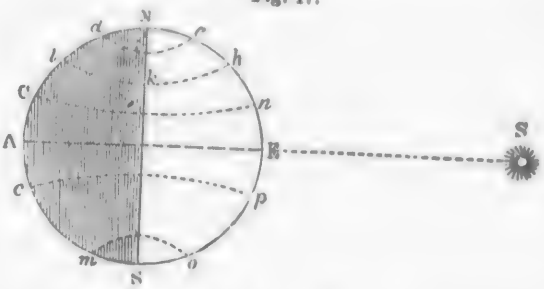
Equal Day and Night over all the Earth.

215. At the equinoxes, the sun is vertical at the equator, or appears in the zenith there, *and the terminator*, always 90° distant from the parallel at which the sun is vertical, *passes through both poles;* and its plane passes through the earth's axis. Then, there is equal day and night over all the earth; for the terminator will cut every parallel equally, and every part will spend half of its rotation without and half within the terminator.

216. This is illustrated by the following figure, which exhibits the state of the world with respect to day and

night when the sun is on the equator. The sun is seen perpendicular to the earth at the equator, the terminator crossing each pole 90° on each side from the point to which the sun is vertical.

Fig. 17.



217. In this figure, it is evident that a point in the dark half, N C S, in revolving from its midnight *l* to its noon *h*, will cross the terminator at *k*, exactly half-way between these two periods—that is, in six hours. The same will take place in passing from *h* back to *l*; and the night and day must therefore be equal on every part of the earth's surface.

218. At the poles at this period the sun will appear to move round the horizon; and, as he thus neither rises nor sets, there will be continual day there. For a short time after, also, as refraction and reflection prolong the day, there will be continual day there, even though he be actually a little below the horizon.

Of the Change in the Length of the Day.

219. The change of the length of the day occurs in the following manner:—When it is said that the sun travels from or to any parallel, it is meant that he travels from being vertical to it, or to being vertical to it.

220. When the sun is vertical to the tropic of Cancer, he is at the farthest north parallel which he reaches

(Fig. 15), and from that travels south from *n* to E and *p*;—by this, the terminator slowly wheels round from *d o* (Fig. 15) to N S (Fig. 17), and then onwards in the same direction till it reaches *e m* (Fig. 16). This brings more and more of the northern hemisphere into the shade, so that each part in revolving is more of its time on the dark side of the terminator, and its day becomes shorter till the terminator comes to *e m*. There the sun ceases its motion south, and begins to retrace his steps from *p* by E to *n*, which causes the terminator also to retrace its course, and move back from *e m* by N S to *d o*. This gradually brings more and more of the northern hemisphere into the illumined half, so that each part in revolving is less of its time on the dark side of the terminator, and its day lengthens till the terminator comes to *d o*, when it begins to move back, and the same series of changes occur again.

221. The exactly opposite series of changes goes on in the southern hemisphere.

222. This is partly illustrated by Fig. 14, page 48, where the sun is represented on its way south, now perpendicular to a point farther south than the tropic of Cancer, and the terminator has advanced to *i v*, towards the poles, and receded from the polar circles. Thus, the day and night will not differ so very much as when the sun is on the tropic, and a smaller circle round each pole will have constant night or constant day.

The following is a summary of these changes.

223. The daily circle through which each person passes in consequence of the earth's rotation, is his *parallel* of *latitude;* and the proportion of his night to his day at any time depends upon the manner in which that parallel lies as regards the **Terminator** (see par. 203).

224. If, in rotating, the terminator does not cross his parallel at all, he will then have *no day*, or *no night*, according as he is on the dark or illumined side of the

terminator; if the terminator cuts his parallel unequally he will have his day and night unequal at that time, but if it cuts his parallel into two equal parts he will then have equal day and night.

225. As every great circle on a sphere cuts every other great circle into two equal parts, the terminator must always cut the equator into two semicircles, one dark, the other illumined, so that *day and night at the equator are always equal*, or, each is of 12 hours' duration.

226. At 20th March and 23d September, the sun is vertical at the equator; so that the terminator passes through both poles and cuts *every parallel* into two equal parts. Hence, there is equal day and night all over the world at these periods, called the **Equinoxes.**

227. At other times, the sun is vertical at some point north or south of the equator; the terminator then *extends beyond* one pole, and *falls short* of the other pole. Some parallels are not cut by it at all;—at these there is no day or no night;—the other parallels are cut unequally, and at these, day and night are unequal.

228. On June 21, the sun is on the north tropic, the north hemisphere is most turned towards the sun, and it is therefore longest day north of the equator, and shortest day south of it. The day gradually shortens in the northern hemisphere and lengthens in the southern till the 22d December, when the sun is on the south tropic, and the southern hemisphere is most turned towards the sun, and it is longest day in the south hemisphere, and shortest day in the north hemisphere. From this position the day gradually shortens in the southern hemisphere, and lengthens in the northern hemisphere, till the 21st of June, when the same series of changes recommence.

229. *Day and night are more nearly equal in proportion as the time is nearer to an equinox, or the place nearer the equator.*

230. From the arctic to the antarctic circle, that is, in the torrid and temperate zones, there is always some day and some night during each rotation (every 24 hours), however unequal they may be.

231. Within the polar circles, at one time there is both day and night in each rotation,—at another, no day, the sun remaining below the horizon for several rotations together,—at another time no night, the sun remaining above the horizon for several rotations together.

232. At the poles, there is six months day, and six months night.

233. The northern and southern hemispheres are always in exactly opposite states, at corresponding latitudes north and south, in respect to day and night.

234. Thus, the sun oscillates backwards and forwards between the tropics, and the terminator oscillates between the opposite sides of the polar circles. When on the tropic of Cancer, the sun is highest above the horizon to those north of the equator; on the tropic of Capricorn, highest to those south of the equator. When on the equator, the sun appears at the same elevation, at corresponding latitudes north and south.

Causes of these Differences and Changes.

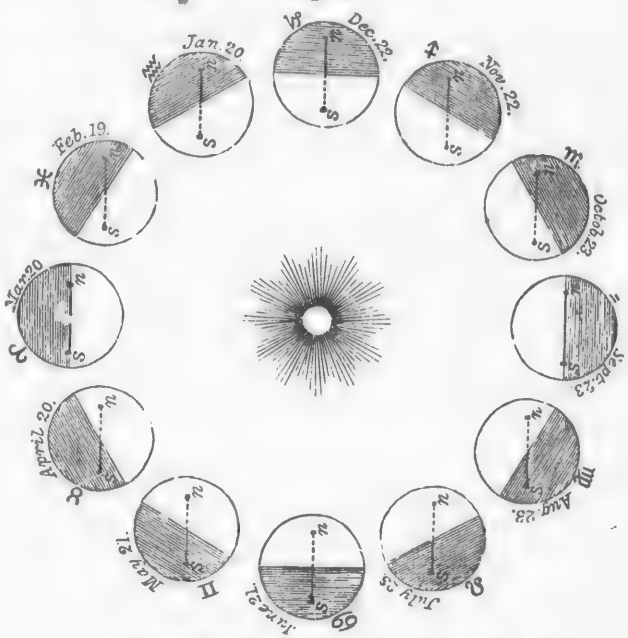
235. Three causes unite to produce these differences in the length of day and night at different places and different times.—1. The earth's annual motion round the sun. 2. The earth's axis being *inclined*, and not perpendicular, to theplane of its orbit. 3. The earth's axis remaining always parallel to itself in all parts of its orbit. These causes place the earth and sun in successive relative positions, which give rise to these changes.

236. From the axis of the earth being inclined to the plane of its orbit, one pole *leans towards* the sun at one period, while the other is *turned from* the sun;

when the earth has moved from that point round one quarter of its orbit, the axis will be placed sideways with respect to the sun, and each pole will be equally turned towards the sun. As the earth advances and completes another quarter, the poles now reverse their relative positions; the pole formerly turned towards the sun is now turned from it; and the other leans towards the sun. On completing another quarter the axis will be again placed sideways towards the sun. As the earth proceeds onward it gradually gets into the position which it occupied at first.

237. This will be better illustrated by the following figure. Let the twelve circles represent the earth in

Fig. 18.



twelve different parts of its course round the sun. Let

the line *n s* represent the axis of the earth or a meridian line, *n* being the north pole, *s* the south pole. The straight edge of the shaded part will represent the terminator, or *the plane of the terminator*, seen always perpendicular to the sun's rays, but varying its position with respect to the axis *n s*, which points in all the positions in the same direction. At the top is seen the position on December 22, the north pole within the dark half, and *turned from* the sun, the south pole in the illumined half, and *leaning towards* the sun. At the left and right, the positions on March 20 and September 23 are represented, the terminator passing through the north and south poles, coinciding with a meridian line, and the axis lying sideways towards the sun, so that each pole is equally under the sun's influence. At the bottom is seen the position on June 21, the north pole in the sun's rays; the south pole in the shade.*

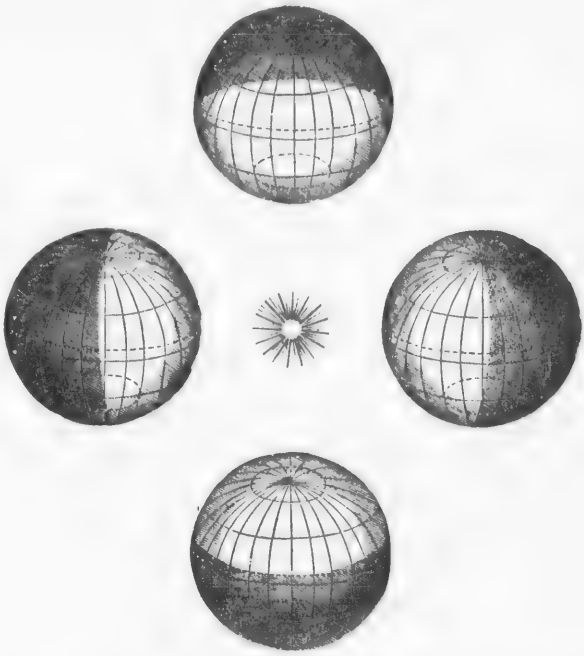
238. The following figure will also illustrate the state of the different parts of the earth at different seasons in regard to light and shade. The terminator is distinctly seen, the gently curved line between the dark and light parts. The north pole is shown at the upper part in each of the four positions, with all the meridian lines radiating from it. At the top it is seen entirely enveloped in darkness, and so that the earth's rotation about its axis does not bring it all out of the shade. At the sides, the terminator is seen passing through both poles, the axis lying sideways towards the sun. At the bottom, the north pole and regions around it are seen entirely in the illumined part, having continual day. The upper position represents December 22, the lower June 21, the *solstices;* — the two sides, March 20, and September 23, the *equinoxes.*

239. The date at each position in Fig. 18 shows the period when the earth gets into each position; and the accompanying character is the astronomical mark for

* An attentive study of the preceding figure, and of the inclination of the axis to the terminator, will convey a precise idea of the various changes. The figure is irregular as a drawing, being a mixture of plan, section, and perspective, but gives a clear view of the effect of the earth's motion round the sun, on the relation of the terminator to the different hemispheres.

the *sign*, or part of the *zodiac* in which the sun appears at the time of the earth entering into each position. Of course, the earth, as seen from the sun, would appear in the opposite sign.

Fig. 15.



240. Thus, the effect of the earth's motion round the sun is to make the latter appear to oscillate backwards and forwards between the highest and lowest positions, shown in Figs. 15 and 16—that is, from being perpendicular to the tropic of Capricorn, *c p*, 23° 28′ south of the equator, on December 22,—to being perpendicular to the tropic of Cancer *C n*, 23° 28′ north of the equator,

on June 21, crossing the equator twice during these oscillations, at March 20 and September 23.*

241. The sun is about 7 days, 16 hours longer in the northern than in the southern half of the ecliptic; being about 187 days in the northern signs, 179 days among the southern signs.

242. The following table shows the length of the longest days in different latitudes, from the equator to the poles:—

			Hours.				Hours.
0°	0′	(Equator)	12	65°	48′		22
16	44		13	66	21		23
30	48		14	66	32		24
41	24		15				Months.
49	2		16	67	23		1
54	31		17	69	51		2
58	27		18	73	40		3
61	19		19	78	11		4
63	23		20	84	5		5
64	50		21	90	0	(Pole)	6

2. Climate.

243. The **Climate** of a place signifies the prevailing character of the weather at that place; that is, the temperature, moisture, atmospheric pressure, winds, electric condition of the air, etc. These, as is well known, are very different at different places.

244. The leading circumstances which determine the character of the climate are,—1. The latitude of the place; that is, its distance from the equator: 2. The height of the place above the level of the sea: 3. Its position with respect to large tracts of land and water: 4. Oceanic currents: 5. The character of the prevailing winds.—Only the first of these can be regarded as an astronomical cause; and it alone requires consideration in this work.

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* From *a* to *o*, Fig. 10, page 26; and then back from *o* to *a*.

245. The climate is warmest about the equator, and becomes gradually colder as the place is farther north or south from the equator, that is, as the latitude increases.

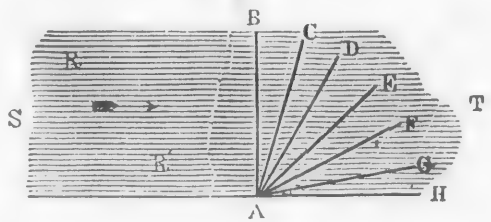
246. This rule is only true *generally*, and of large changes in latitude. Considerable deviations from it are produced by the other causes.

247. The position of the different latitudes, *in respect to the sun's rays*, is the cause of these differences in climate.

248. The heat at any place is in proportion to the number of the sun's rays which fall upon it; and the number of rays which it receives (other things being equal) depends upon the *direction in which they fall.* Any surface receives more rays the more perpendicularly they strike upon it, and less, in proportion as the rays fall more obliquely; that is, as the angle they form with it is further from a right angle.

249. This may be illustrated by the following figure.

Fig. 20.



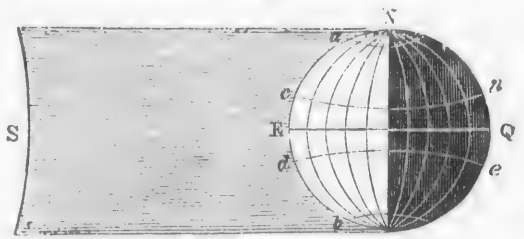
Let R and R′ be rays proceeding in the direction from S towards T, and falling upon the equal surfaces A B, A C, A D, A E, A F, etc., all lying in different directions. It is plain that more rays fall upon the surface A B, which is perpendicular to the direction of the rays, than on any other; that A C, which is nearest to the perpendicular, receives more than A D, A D more than A E, and so on; more rays being received in

proportion as the surface is nearer to being perpendicular to the rays.

250. As the sun oscillates between the tropics, continually vertical to some parallel in the torrid zone, his rays always fall perpendicularly at some parallel between the tropics, and less so as the parallel is further north of the north tropic, or south of the south tropic. Accordingly, more rays are received in a given space at the torrid zone, than in an equal space north or south; so that the temperature is always higher there than anywhere else. And as fewer rays are received in proportion as the place is further to the north or south, the heat must diminish in these directions.

251. This is illustrated by the following figure. Let S represent the sun, E the earth's equator, *c*, *d* the

Fig. 21.



tropics, *a*, *b* the polar circles, N the north pole. It is seen that the earth's surface at the equator is perpendicular to the sun's rays, the zone between the tropics more nearly perpendicular to the sun's rays than any parts north or south, while all the other parts are much inclined; that they are more inclined as they are further from the equator, the rays towards the poles only skirting the ground.

252. The air absorbs part of the sun's rays,—little in the upper strata, but a considerable portion in the dense lower strata loaded with vapour. Hence, from this

cause also, less of the sun's rays strike upon a place in proportion to the quantity of atmosphere through which they pass, and in proportion to the density of that atmosphere. Perpendicular rays pass through least of the air before coming to the ground. Oblique rays not only pass through more air, but through a larger proportion of the dense parts, so that a much greater portion is absorbed before they strike the soil.

253 The diminution of the mean temperature in passing from the equator to the poles, so far as this is regulated by the solar influence, is in proportion to the square of the cosine of the latitude. The change is, therefore, slight from the equator towards either tropic, greatest about lat. 45°, and slight from the polar circles to the poles.

3. The Seasons.

254. That regular alternation of different kinds of weather which takes place at any place during the year is termed *change in season.*

255. The same causes which give rise to the change in the length of the day and to differences in climate, produce the change in the seasons. The sun imparts more heat in proportion; 1. as he is higher above the horizon of a place, and his rays fall more perpendicularly; 2. as he is longer in the day above the horizon of a place. In the northern hemisphere, the sun rises higher and remains longer above the horizon, from March to September: we have warm weather, or **summer,** then. From September to March the sun's rays fall in a more slanting direction, and he is a shorter time daily above the horizon: there is cold weather, or **winter,** then, in the northern hemisphere.

256. The southern hemisphere is in exactly the reverse state then—summer during our winter, winter during our summer.

257. This is illustrated by Figs. 15 and 16. In Fig. 15 the sun's rays fall more perpendicularly on the

northern hemisphere, and slantingly on the southern hemisphere. In Fig. 16 the reverse is seen. In Fig. 17 and Fig. 21, the relative position of the sun and earth at the equinoxes is shown—the sun vertical at the equator, the rays more and more slanting as the place is further north or south.

258. It is evident that if the axis of the earth were perpendicular to the plane of its orbit, each parallel would always be turned in the same degree towards the sun, and we would therefore have *no change in its seasons.* It is the inclination of the axis that causes the same parallel to lie differently towards the sun in different parts of the orbit. Hence, in a planet such as Jupiter or the moon, where the axis is perpendicular to the plane of the orbit, there can be no change in seasons; while in Venus, where the axis is very much inclined, the change is very great,—so great that a marked difference prevails between the state of the equatorial regions at the equinoxes and solstices. From this, the equatorial regions have *two winters* at the solstices, and *two summers* at the equinoxes. The same prevails on the earth in a slight degree—but it is very marked at Venus, from her tropics being so far from her equator.

259. The sun being nearer to the earth in our winter than in our summer, it might be supposed that the weather should be warmer over all the world then. But this makes no difference; for, as much heat is lost by our more rapid motion in winter as is gained by our greater proximity to the sun then; and in summer, while there is less heat from our greater distance, this is compensated for by our slower motion.

260. The warmest part of the season is not when the sun is highest and longest above the horizon; nor the coldest, when the sun is lowest and the day shortest—but some weeks after these periods. The reasons of this are, that the heat must *increase*, so long as the earth receives more heat during the day than it parts with during the night; and this is the case for a considerable time after the longest day: and that the tempera-

ture must *decrease*, so long as more heat is lost during the night than is gained during the day; which goes on for several weeks after the shortest day.

261. In like manner, the warmest part of the day is not at noon, when the sun is highest, and his rays fall most perpendicularly, but some little time after, about 2 P.M. The reason is, that till that period the heat received is greater than what is lost,* so that the temperature must rise till that time, although less new heat is received then than at noon. And the coldest time during the night is about an hour before sunrise, up to which time the earth has continually been losing heat, without receiving any.

SECTION III.

Trade-Winds and the Tides.

262. There are certain uniform and continual motions of the atmosphere and the ocean, which are produced by astronomical causes, and are therefore proper subjects of consideration in a treatise on Astronomy.—These are the *Trade-Winds* and the *Tides*.

1. Trade-Winds.

263. In certain districts between the tropics, the winds blow regularly in a north-east and south-east direction,—*north-east* north of the equator, *south-east* south of the equator. These steady winds are called the **Trade-winds**.

264. The trade-winds are caused by the great currents which are continually rushing from the polar and temperate regions towards the equator, modified by the earth's rotation from west to east.

265. Owing to the great heat which prevails in the

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* It must be observed that *heat is at all times passing out from bodies*, and that a body's temperature depends upon the proportion between what is received and what is given out; rising in temperature if heat is absorbed more rapidly than thrown off, and falling in temperature if more heat is given out than is received.

equatorial regions, the air there is expanded, and therefore specifically lighter than the air further north or south; which, being colder and heavier, rushes towards and displaces the warm air of the torrid zone. This produces continual currents towards the equator from the north and south latitudes. These are the source of the trade-winds, which, were there no other cause influencing them, would be in a due north and due south direction.

266. Now, the air from any place partakes of the motion of the earth at that place; and the parts have most rapid motion in proportion as they are nearer the equator (being there furthest from the axis—185). Accordingly, any current of air which proceeds towards the equator, will have a slower rotatory motion than the parts to which it is tending. *It will therefore cause an apparent current in a direction opposite to that in which the earth is moving*—that is, appear to blow in an *easterly* direction, as the earth revolves in a westerly direction. The easterly direction which the wind thus acquires, combined with its *northerly* direction, gives the invariable *north-easterly* wind in certain regions of the *northern hemisphere*—combined with its southerly direction in the southern hemisphere, gives the *south-east* trade-wind which is found south of the equator.

267. If we suppose the air at any place to be at rest while the earth continues its rotation, an individual at that place would experience a wind in the direction opposite to its motion, as the effect is the same whether the air move and the individual stand still—or the air stand still and the individual rush against it. Now, it will be the same sort of effect, though less in degree, when the air is moving *in the same direction as any part of the earth's surface, but with a slower motion*—the place will overtake it, rush against it, and cause a wind in an opposite direction. If this air have, besides the slow motion in the *same direction*, another in a different direction, the two will be compounded into a middle course, according to the law of the composition of forces. Thus it is with the current which produces the trade-wind. It has a *slow westerly* motion, which produces an easterly wind in a place having a *rapid westerly*

motion; which easterly wind, combined with its north or south motion, gives the north-east or south-east trade-wind.

268. As the distance from the axis increases very little in the vicinity of the equator, the rotatory motion will increase very slightly there, and there will be little addition to the easterly direction of the current created about the equator; and as the air gradually acquires the motion of the parts it is over, it will have acquired the increased motion of the equatorial parts by the time it reaches them; the easterly direction will diminish as they come near the equator, and the north and south currents meeting there, the two will neutralize each other; accordingly there is a zone of comparative calm, or irregular breezes, in the immediate vicinity of the equator—at about 3° to 10° north latitude (see par. 270).

269. The heated air which ascends from the equatorial regions gradually descends towards the earth's surface; and, bringing to the parts where it descends a higher velocity than they possess, moves in advance of them, in the same direction, and constitutes a sort of trade-wind; which, compounded of the westerly motion of rotation and the motion from the equator, gives a south-westerly direction in the temperate regions of the northern hemisphere: a north-westerly direction in the temperate regions south of the equator.

270. These are the leading causes which give rise to the trade-winds. They are modified in various ways by many local circumstances, the consideration of which belongs to physical geography.

2. The Tides.

271. By **the tides** we mean that regular succession of rise and fall of the surface of the waters of the globe, which is observed in all the great oceans, and in the seas and rivers which freely communicate with the oceans.

272. "It is a very remarkable operation of nature, that we observe on the shores of the ocean, when, in the calmest weather and most serene sky, the vast body of waters that bathe our coasts advances on our shores, inundating all the flat sands, rising to a considerable height, and then as gradually retiring again to the bed of the ocean; and all this without the appearance of any cause to impel the waters to our shores, and again to draw them off. Twice every day is this repeated. In many places, this motion of the waters is tremendous, the sea advancing, even in the calmest weather, with a high surge, rolling along the flats with resistless violence, and rising to the height of many fathoms."—*Robinson's Mechanical Philosophy.*

273. When the waters rise to the highest point which they reach in the course of the day, it is said to be **high water,** or **flood,** and the rising is called the **flood-tide**; when at the lowest, **low water,** or **ebb,** and the fall is termed **ebb-tide.** The highest or fullest *flood* is called a **spring-tide**; the lowest *flood* is termed **neap-tide.** The tide on the side of the earth next the moon, is called the **superior tide**; that on the opposite side, the **inferior tide.**

274. The phenomena of the tides are produced by the joint action of the moon and the sun upon the waters of the ocean; chiefly by the moon. The attractive force of these bodies is sufficiently strong to draw slightly towards them those parts of the earth which are movable, and whose particles can easily be made to slide over each other;—that is, the waters.

The following are the leading phenomena of the tides.

275. (1.) The waters when at their highest, gradually sink for about $6^{h.}\ 12^{m.}$ when it is *low water*, and from this gradually rises again for $6^{h.}\ 12^{m.}$ when it is *high water*, then sink again, rise again, and so on unremittingly. Upon an average, the tide ebbs in about 10 minutes less than the time it takes to rise, and remains stationary for a little at ebb and at flood. The whole period between two successive *floods*, or between two successive *ebbs*, is about 12 hours 25 minutes. The

interval between two successive floods is 12 hours 19 minutes at new and at full moon; 12 hours 30 minutes at the quarters.

276. Thus during every 24 hours and 50 minutes there is high water twice and low water twice at every place, and the flood is about three-quarters of an hour later every day. Hence, therefore, as the earth turns half round in that time, 12 hours, there must be high water at the opposite parts of the earth's surface at the same time—that is, at the two places having the same meridian circle (or on the opposite meridians, reckoned by their numbers).

277. (2.) The height of high water, as well as that of low water, varies very considerably, but regularly. But, when the tide rises highest, it falls lowest, and when it rises least, falls least. At Plymouth, there is sometimes a difference of 21 feet between high and low water; sometimes only 12 feet.

278. The highest or *spring-tide* occurs once every fortnight, and is usually about the third or fourth high tide after new moon, and the third after full moon —about a day and a half to two days and a half after these periods.

279. The lowest tide,* or *neap-tide*, also occurs once every fortnight, being the third or fourth high tide after the moon is in her quarters—from about a day and a half to two days and a half after these periods.

280. The tides gradually decrease from about new moon to the first quarter, increase from the first quarter to full moon, decrease from full moon to the third quarter, and again increase from the third quarter to new moon.

281. (3.) There is also a *monthly* period of change in the height of the tides: the highest spring-tide is that which occurs when the moon is in *perigee* (nearest

* That is, when the water falls least and rises least.

to the earth); and the next spring-tide is the smallest, occurring when the moon is in *apogee* (farthest from the earth). The force of the moon's attraction being the main cause of the tides, it is to be expected that they will vary somewhat as her distance varies.

282. (4.) The height of the tides is also affected by the following causes: the sun's distance;* the elevation of the sun and moon; the latitude of the place; the local circumstances, such as banks in the ocean, and the form and elevation of the shores, channels, currents of rivers, winds, etc.

High Water at the Part nearest to the Moon.

283. The chief cause of the phenomena of the tides is the *force of the moon's attraction.* The waters under the moon (*i. e.*, at the place where the moon is on the meridian) are attracted towards her, while the waters at the sides, where the moon appears in the horizon, are also drawn towards that part, forming *high water* there. As, by the earth's rotation and moon's motion, the moon comes on the meridian of each place once in 24 hours 50 minutes, there will be high water everywhere once in every period of 24 hours 50 minutes

284. The period of high water will not be exactly when the moon is on the meridian and her action strongest; for, the impetus the waters have received, and the continuance of the moon's action (still strong, though decreasing), cause them to continue rising for some time after. The period of high water, therefore, is usually (local causes being disregarded) from two to three hours after the moon is on the meridian. At new moon, the sun and moon cross the meridian together, at noon. At full moon she crosses the meridian at

* The greatest tides are during the winter of the northern hemisphere, the sun being nearest to the earth then. Also, the tides are highest in the latitudes about the equator,—the least within the polar circles.

midnight — when in her quarters, at 6 o'clock, A.M. or P.M.

Low Water where the Moon is in the Horizon.

285. As the moon tends to draw the waters in straight lines towards her, she will evidently draw off the surface, or depress the waters on which she acts sideways; *i.e.*, those parts at which she appears in the horizon, 90° on each side from the meridian she is on; this will cause *low water* at these two places once every 12 hours 25 minutes.

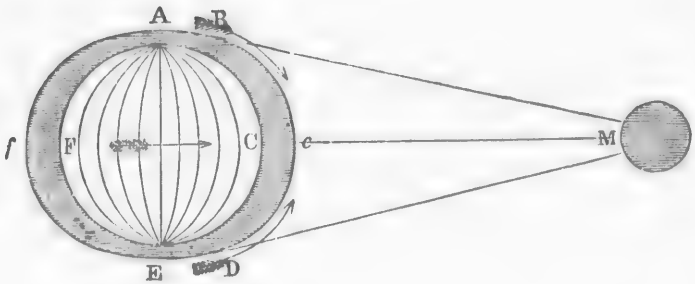
High Water at the Part furthest from the Moon.

286. As the moon attracts the earth, as well as the loose waters on its surface, she will tend to draw the earth *from* the waters which are on the side of the earth most distant from the moon. As she attracts the earth more forcibly, being nearer, than those distant waters, she will draw the earth further towards her than those waters. This will cause the earth to recede from under these waters, which causes them to rise relatively to the land at those parts, and thus there is high water there also. As the moon comes into this position every 24 hours 50 minutes, there will be high water at the part farthest from the moon once in every period of 24 hours 50 minutes.

287. This accounts for the **two tides** daily; each part, by the earth's daily rotation, being brought once *near* to and once *remote* from the moon during each 24 hours 50 minutes.

288. The following diagram will illustrate the action of the moon upon the waters.

Fig. 22.



Let A B C D E F represent the earth, M the moon, C the point nearest to the moon, F the meridian farthest from the moon, A and E the points at which the moon appears in the horizon, 90° east and west from C and F; then there will be high water at C and F; low water at A and E.

289. The moon's attractive force at C evidently tends to raise the waters towards *c*, and to draw them from A to B, E to D, and from B and D towards *c;* as shown by the arrows in Fig. 22. Also, as the moon's force draws the earth from F with more force than it draws the waters at F, the earth must recede from these loose waters and cause them to be proportionally elevated. Hence, there is high water at C, where the moon is on the meridian, and also at the opposite meridian F.

290. But the moon's action evidently draws the waters *from* A and E, and tends to make them low at these points: while these waters tend also to rush towards F, where, from the earth's recession, the waters are lighter. These two causes depress the waters at A and E, and there is therefore low water there.

291. The action will be readily understood, if we reflect on the simple law of the diminution of the force of attraction as the distance increases; and bear in mind that the earth is less

attracted by the moon than the waters near her, but more than the waters more remote.

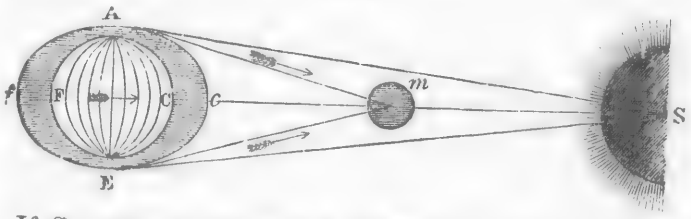
Sun's Action upon the Tides.

292. The sun also by his action influences the waters of the ocean, and is the main cause of those regular changes in the height of the tides which are everywhere observed.

293. His action raises the tides higher than usual when it unites with that of the moon,—renders them lower when his action is opposed to that of the moon. At new moon and full moon, the action of the sun and moon coincide. At the quarters, they are opposed in their action. Therefore there are *spring-tides* at new and full moon, *neap-tides* at the quarters.

294. This will be readily understood from the following figures.

Fig. 23.



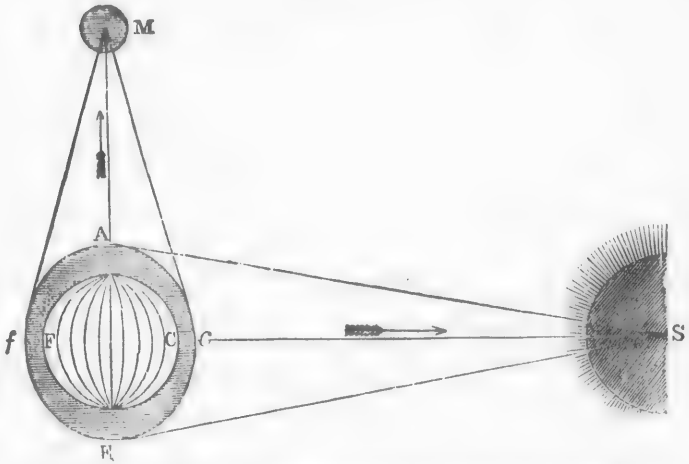
If S represent the sun, *m* the moon, and *f* A *c* E the earth, then, as the sun and moon act in the same manner and in the same direction, it is evident that their effect upon the waters will be increased, or there will be a *spring-tide* at *c* and *f*, and very low water at A and E. Both sun and moon tend to raise *c* and *f*, to depress A and E.

295. But if the moon be in one of her quarters, as in Fig. 24, then they act in opposition to each other. The sun tends to draw the waters towards *c* from A and E; and thus prevents the tide at A and E from being so

high, and that at *c* from being so low,—or forms *neap-tides*. The moon tends to raise A and E, to depress *c* and *f*,—the sun exactly the reverse.

296. The ratio of the sun's action on the tides to that of the moon is as 38 to 100, while the ratio of spring-tides to neap-tides is as 138 to 62.

Fig. 24.



297. The Baltic Sea has no perceptible tides; and that in the Mediterranean Sea is very slight. These seas have no tides in themselves, because, being of comparatively small extent, the moon's action is equal at every part, and they do not receive the influence of the Atlantic tide, because their entrances are narrow, and do not lie in the direction of the current produced by that great tidal wave.

SECTION IV.

Divisions of Time.

298. The leading divisions of time are, the **Day,**

the **Month**, and the **Year.** The civil standard, in the reckoning of time, is the **Mean Solar Day** of twenty-four hours; that is, the mean or average time which the earth takes in revolving from the moment when the sun is on the meridian of a place till he returns to that meridian again. The most perfect measure of time is the sidereal day, or the time which the earth takes in revolving from the moment when any star is on the meridian of a place till it returns to the same meridian.

1. The Day.

299. There are four different kinds of days. 1. The sidereal day. 2. The solar day. 3. The mean solar day. 4. The lunar day.

1. Sidereal Day.

300. The sidereal day is the true time of one complete rotation of the earth on its axis,—and its length is 23 hours, 56 minutes, 4·09 seconds. It is called "sidereal" from *sidus*, a star, because it is determined by the interval between the two successive appulses of any star to the same meridian.

301. The true time of the earth's rotation on its axis is judged of from the return of a star to the meridian, because the distance from the earth to the fixed stars is so great, that its position in *the most distant parts of its orbit may be considered always the same with respect to any fixed star.* Hence, in reference to the fixed stars, the earth may be looked on as not moving round the sun at all, but *ever remaining in the same spot*, rotating at a uniform rate upon its axis, and therefore ever returning to any star in the same time.

2. Solar Day.

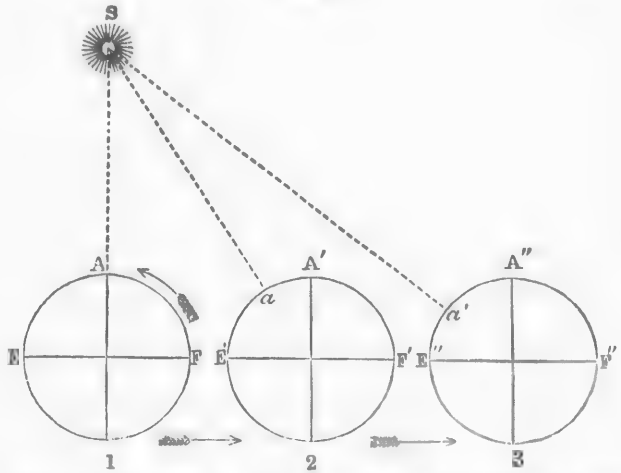
302. The solar day is the time from the sun's being on the meridian of a place till he returns to that meri-

dian,—in other words, the interval between two successive appulses of the sun to the same meridian.

303. The solar day is longer than the sidereal day, and its duration is different at different periods of the year.

304. The solar day is longer than the sidereal day, because, while the earth's motion onwards in its orbit *makes no sensible change in its position in relation to the fixed stars, it makes a material difference in its position in relation to the sun.* This affects the solar day in the following manner: After the earth has made one complete turn on its axis, and brought any meridian on which the sun and any star were at the commencement of that rotation to the same star, *that meridian will not have reached the sun at the close of the rotation;* for, the earth has during that period moved onward in its orbit and, having in a manner *moved past the sun*, must turn further round than the complete rotation to bring that meridian to the sun again.

Fig. 25.



305. This may be illustrated by the above figure.

Let S represent the sun, E A F, a section of the earth through the equator, A the meridian on which the sun is at any given time. If the earth revolve on its axis in the direction F A E, as indicated by the arrows, and move in its orbit from 1 to 2 in the time in which it turns on its axis, it will have moved to 2 when the point A or A′ has returned to the same star; but as it has moved so as to place the sun in a manner *behind* its new position, it will not have brought that point to the sun, but require to move round to *a* before that meridian comes again to the sun. Hence, the solar day is longer than the sidereal day by the time the point A′ takes in revolving from A′ to *a*.

306. The length of the solar day is different at different periods of the year from two causes :—1. The inequality in the rate of the earth's motion round the sun ;—2. The inclination of the earth's axis to the plane of its orbit.

307. As the earth does not always move at the same rate round the sun, it will, at different times, have moved different distances during one rotation, and therefore the excess over the complete rotation necessary to bring a point back to the sun will be more at certain times than at others.

308. Thus, if the earth, instead of moving from 1 to 2 (Fig. 25), during one rotation, had moved from 1 to 3, the point A, or A″, at the end of the rotation, would be still further from the sun, and have to move further besides the complete rotation to bring A to have the sun on its meridian—namely to *a′*.

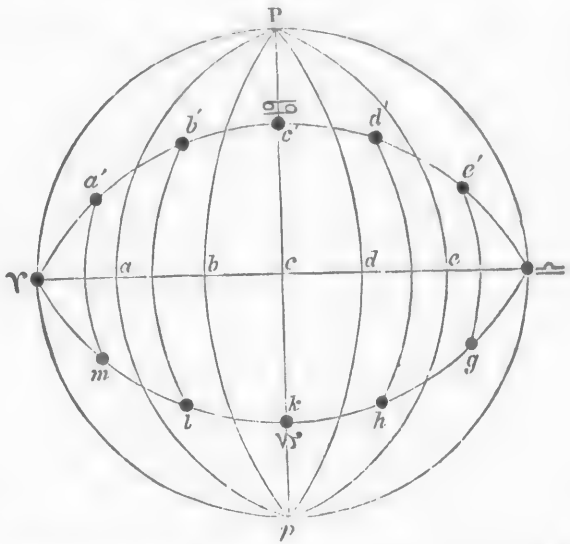
309. Perhaps the best illustration of the difference between the solar and sidereal days is afforded by the motion of the hands of a watch or clock. If both hands be at twelve o'clock, and set out together from that point, the long or minute hand, when it has made a complete revolution, will have returned again to 12 o'clock, but will not have reached the hour hand, because it also has been moving, though more slowly, in the same direction; and the long hand will have to go more than the complete circle before it overtakes the short hand. Now, the long hand resembles any terrestrial meridian, the short hand

the sun, and the dial-plate and figures the starry sphere and stars. If the hour hand be supposed to move at different rates in different parts of its circuit, the minute hand must take different periods to come up to it.

310. The inclination of the earth's axis to the plane of its orbit affects the length of the day by causing the earth to move in a plane inclined to that of its equator; that is, inclined to the direction of the earth's rotatory motion, which is parallel to its equator.

311. This will be best explained by the supposition that (as it really appears) the sun moves round the earth in the ecliptic, while the earth turns daily on its axis; and that while the real sun moves in the ecliptic, another, which marks uniform time, moves in the equinoctial. With these suppositions, and the aid of the following figure, the inequality caused by the sun being

Fig. 26.



in the ecliptic may be comprehended. Let the figure

represent the sphere of the heavens,* ♈ *c* ♎ the equinoctial, and ♈ *c′* ♎ the ecliptic. Let the real sun be supposed to move from ♈ by *a′ b′ c′ d′ e′* ♎ *g h l m*, returning to ♈ in the year, while the other, starting at the same time from ♈, moves along the equinoctial by *a b c d e* ♎, returning again in the opposite direction in the year. The ecliptic and equinoctial are great circles of the same sphere, and hence are equal to each other. Let each be divided into the same number of equal parts in *a*, *a′*, etc.; then, as the whole circles are equal, the parts in one will be equal to those in the other, and therefore the part ♈ *a′* of the ecliptic is equal to the part ♈ *a* of the equinoctial, *a′ b′* to *a b*, *b′ c′* to *b c*, and so on.

312. Now, let the meridian of any place and the two suns be on ♈ at any given moment—then all set out together in the same direction, *i.e.*, towards ♎. When the place has completed its daily revolution and returned to ♈, the two suns will have advanced in their course, let us suppose to *a′* and *a*, equal distances from ♈,—in continuing its revolution, it is plain that the meridian of the place will come sooner to the sun *a′* than to *a*, as the latter is furthest,† *in the direction of rotation*, from the meridian line of the place. Hence, the time, as marked by the sun in the ecliptic, will be before that as marked by the sun in the equinoctial; and this goes on so long as the sun is increasing his distance from the equinoctial—that is, from ♈ to *c′*. When he comes to the solstice at *c′*, the reverse takes place; the meridian, from *c′* to ♎, comes to the sun *d* on the equinoctial before *d′* in the ecliptic.—The same takes place again when the sun moves from ♎ by *g*, *h*, etc., to ♈.

313. The **sun-dial** exhibits time as indicated by the

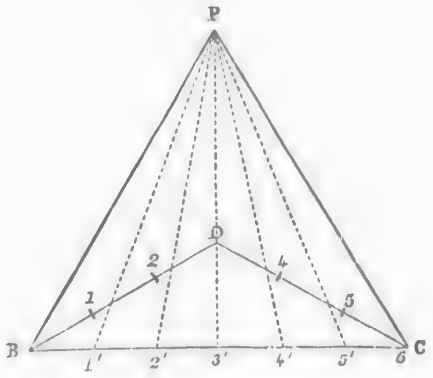
* ♈ is Aries; ♋ Cancer; ♎ Libra; and ♑ Capricorn.

† The distance of a point from a line is the perpendicular on the line drawn from the point.

real time of the sun being on the meridian,—the actual solar day, sometimes longer, sometimes shorter. The **clock** exhibits time adjusted to the mean solar day.

314. The comprehension of the variation in the day being caused by the sun's motion in the ecliptic, will be greatly aided by marking points on the equinoctial and ecliptic at equal distances from the equinox, on a terrestial or celestial globe, and observing in what order they come to the brazen meridian, according as they are approaching to or receding from the equinoctial. It may be rudely illustrated by making a figure such as the following (Fig. 27),—fixing by a pin one end of a thread at P, and causing it to pass from P B to P C. The thread, in passing from P B to P 3', will always come sooner to any point in B D than to a corresponding one in B 3', and the reverse in passing from P 3' to P C. Now P represents the pole, the thread the meridian of a place, B D C the ecliptic, B C the equinoctial.

Fig. 27.



3. Mean Solar Day.

315. The mean time occupied by the earth in revolving from the sun's being on the meridian of a place till it returns to the same meridian, is called the *mean solar day*. It is this to which the clocks are adjusted, so that they may give equal time at all periods of the year.

316. Four times a year, the *mean solar day* and

actual solar day are the same. Then, the clock (mean solar day) and sun-dial (actual solar day) are coincident. These four times are, December 24, April 15, June 15, September 1.

317. These periods are near the equinoxes, but do not coincide with them. Did the variation in the solar day depend solely on the inclination of the earth's axis to the ecliptic, the periods of the clock and sun being the same would be the equinoxes and solstices; but the other element which gives rise to variation in the solar day—the inequality in the rate of the earth's motion round the sun—causes the times of coincidence of clock and sun to deviate a little from the equinoxes and solstices.

318. From December 24 to April 15, and from June 15 to September 1, the mean solar day is shorter than the actual solar day,—the sun takes longer than 24 hours between two successive appulses to the same meridian,—apparent time is behind mean time,—or, the clock is *before* the sun.

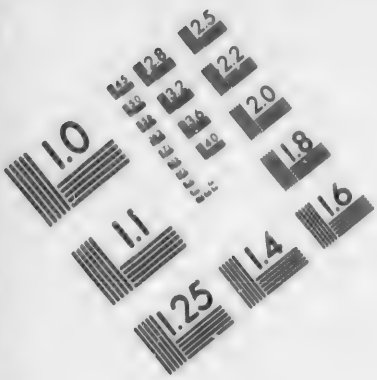
That is, from about c' to $\simeq$, and k to Υ in Fig. 26. In these quarters of its course, the meridian of a place comes to the sun in the equinoctial before it reaches that in the ecliptic.

319. From April 15 to June 15, and from September 1 to December 24, the actual solar day is *shorter* than the mean solar day,—the sun occupies less than 24 hours between two successive appulses to the same meridian,—apparent time is before mean time,—or, the clock is *behind* the sun.

That is, from about Υ to c', and $\simeq$ to k, Fig. 26, a place in its daily revolution comes sooner to the real sun in the ecliptic than to the imaginary sun we have supposed to revolve in the equinoctial.

320. See column "Equation of Time" in the almanacs; which shows how much the clock is before or behind the sun every day of the year, so that when we take the true time by an observation of the sun's altitude, we may be able to add or subtract the necessary time to set the clock by mean time.

321. Generally speaking, it may be said that from about the time of the equinoxes, the clock is behind the



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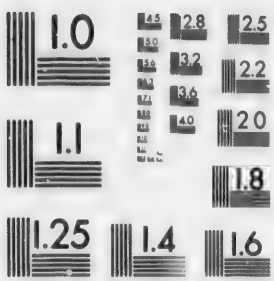

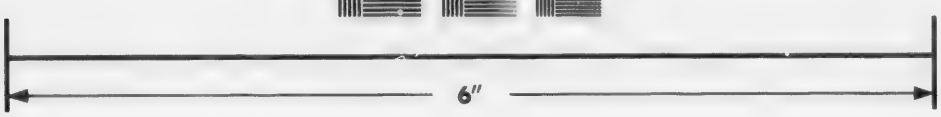

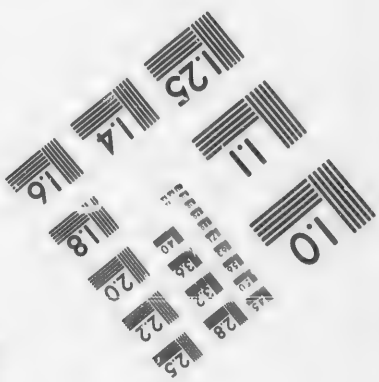

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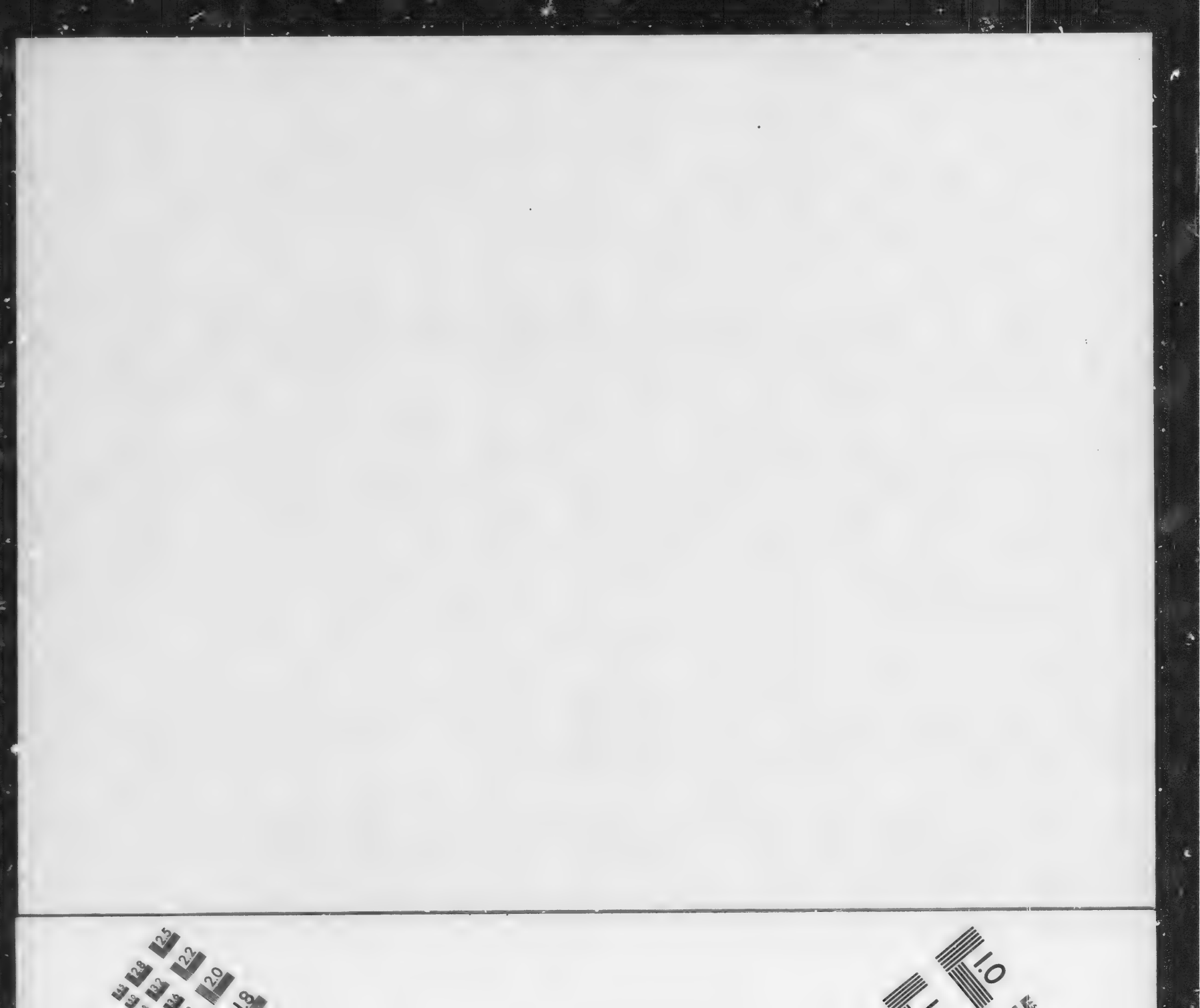


sun,—from about the time of the solstices, the clock is before the sun. The days vary so much, that sometimes apparent noon is $16\frac{1}{4}^{m.}$ before mean noon,—sometimes $14\frac{1}{2}^{m.}$ after mean noon.

322. Although the sidereal day never varies, it cannot be adopted as the standard of time for ordinary occasions of life; because it would not conform with those natural divisions into day and night (periods of sunshine and periods of darkness) from which, for the sake of convenience, our arrangement of time cannot depart far. As the stars always come to the meridian at the same successive intervals, and the sun does not,—if the hours were regulated by the sidereal day, the same hour would now be at sunrise, now at noon, now at sunset, continually changing its relation to the occurrence of those changes of the day and night, by which it is most convenient to divide our time.

4. Lunar Day.

323. The lunar day is the interval between two successive appulses of the moon to the same meridian. This is different from the true day, as the moon has a motion through the heavens, so that the earth has to make more than a complete rotation before she brings any meridian again round to the moon. As the moon moves daily about 13° through the sky, to overtake which the earth requires about 50 minutes, this time must be added to the common day to constitute a lunar day; which is theaefore $24^{h.}\ 50^{m.}$ in duration.

2. The Month.

324. The month is of three kinds,—the *sidereal*, or *periodical month*, of 27 days, 7 hours, 43 minutes; the *synodical*, or *lunar month*, of 29 days, 12 hours, 44 minutes, being the interval from one new moon to the next (335); and the calendar, or common month, January, February, March, etc., 31 or 30 days, excepting February, which is 28 or 29 days. In each year there are 12 common or calendar months; a little less

than $12\frac{1}{2}$ synodical months; and a little less than $13\frac{1}{2}$ sidereal months.

3. The Year.

325. The year is of five kinds,—1. The **equinoctial, or tropical year**;—2. The **sidereal year**;—3. The **anomalistic year**;—4. The **common year,** of 365 days;—5. The **leap year,** of 366 days.

1. The Tropical Year.

326. The period of time adopted for the astronomical year is the interval between two returns of the sun to the same **equinox**; called, therefore, the equinoctial year. Its duration is 365 days, 5 hours, 48 minutes, and 49·7 seconds.

327. The **calendar** or **common** year contains 365 days. The odd hours, $5^{h}\cdot 48^{m}\cdot 49{\cdot}7^{s}$, would soon accumulate to a serious amount of error: and, by a change of about a day in four years, would gradually throw the seasons forward, so as to arrive later each year, till they would no longer occur at the same months as at present; and this change would be continually going on, the fixed relation between the *months* and the *seasons* being destroyed. To prevent this inconvenience, the odd hours are disposed of as follows: They amount to nearly a quarter of a day, and are allowed to accumulate till *every fourth year*, when they amount to a day, and are got rid of by making that year one day longer, or 366 days. That additional day is added in February, which has then 29 days: and that year is called **leap year,** or **bissextile.** This and other important improvements were introduced by **Julius Cæsar,** according to the plans of the astronomer **Sosigenes.**

328. But the excess of the tropical year over 365 days is not quite a quarter of a day, being 11 minutes 10 seconds less; hence one day every four years is too much to add, and causes an excess of one day in about

135 years. This is compensated for, within a very trifling quantity, *by making every hundredth year a common year, except the fourth, which is to be a leap year.* Thus in every four hundred years (3 times 135 = 405), three years, which would otherwise be leap years, have only 365 days, which takes off the excess of the day added in each leap year over four times $5^{h.}\ 48^{m.}\ 49{\cdot}7^{s.}$ The remaining error amounts only to one day of excess in 3866 years.

The principle of arrangement may be thus shortly stated. Every common year which leaves no remainder when divided by 4 (as the year 1872), and every hundredth year (years ending in 00), which leaves no remainder when divided by 400 (as the year 2000), are leap years, having 366 days. All the others are years of 365 days. Thus, 1600, 2000, 2400, are leap years; but 1700, 1800, 1900, 2100, 2200, 2300 are ordinary years.

329. This arrangement was introduced by Pope Gregory XVI. in 1582, and has been adopted in all civilized countries, except Russia. It was introduced into Great Britain in 1752,—being termed the *new style.* The error had then accumulated to 11 days, and was rectified by advancing the days of the month 11 days: the 3d of September to be the 14th. The difference between the new and old styles now amounts to 12 days.

2. The Sidereal Year.

330. The true time of the earth's revolution in its orbit, is the period of its return to the same star. After the sun has returned to the same equinox, as that has receded $50{\cdot}1''$ (by the precession of the equinoxes,—which see), he has still $50{\cdot}1''$ of his orbit to complete the real revolution, which requires $20^{m.}\ 19{\cdot}9^{s.}$ of time, which must therefore be added to the tropical year to

make the sidereal year. The duration of the latter is therefore, $365^{d.}\ 6^{h.}\ 9^{m.}\ 9{\cdot}6^{s.}$

3. The Anomalistic Year.

331. The line of the earth's aphelion and perihelion —that is, the longer axis of the orbit—undergoes a gradual change, which shifts the perihelion $11''{\cdot}8$ annually. The earth, therefore, must describe this small arc in addition to its real revolution to bring it round to the perihelion again. It requires $4^{m.}\ 39{\cdot}7^{s.}$ to complete this small arc, and therefore the anomalistic year—as the time required to bring the earth to the same relative position to the major axis of its orbit is called—is $4^{m.}\ 39{\cdot}7^{s.}$ more than the sidereal year, or $365^{d.}\ 6^{h.}\ 13^{m.}\ 49{\cdot}3^{s.}$

332. The following table exhibits the leading divisions of time:—

Standards of Time.

	Hours.	Minutes.	Seconds.
Rotation of earth on axis	23	56	4·09
Vibration of pendulum 39·13 inches long at the lat. of London, 51° 30′ N. .	0	0	1
Civil day, 86400 of the above seconds (divided into 24 *hours* of 3600 such seconds each; and each hour divided into 60 *minutes*, composed of 60 such seconds)	24	0	0

Days.

Sidereal day (as above)	23	56	4·09
Solar day, more or less than	24	0	0
Mean solar day (civil day)	24	0	0
Lunar day	24	50	0

Months.

	Days.	Hours.	Minutes.
Sidereal month	27	7	43
Lunar month	29	12	44

Calendar month, 31, 30, 29, or 28 days.

Years.	Days.	Hours.	Minutes.	Secs.
Sidereal year	365	6	9	9
Equinoctial year	365	5	48	49
Calendar year	365	0	0	0
Leap year	366	0	0	0

SECTION V.

MOON'S PHASES.—ECLIPSES, ETC.

1. The Moon's Phases.

333. The changes in the moon's appearance, from a small illumined crescent to that of a full enlightened orb, and from that to a crescent again till she disappears entirely, are termed **phases**.

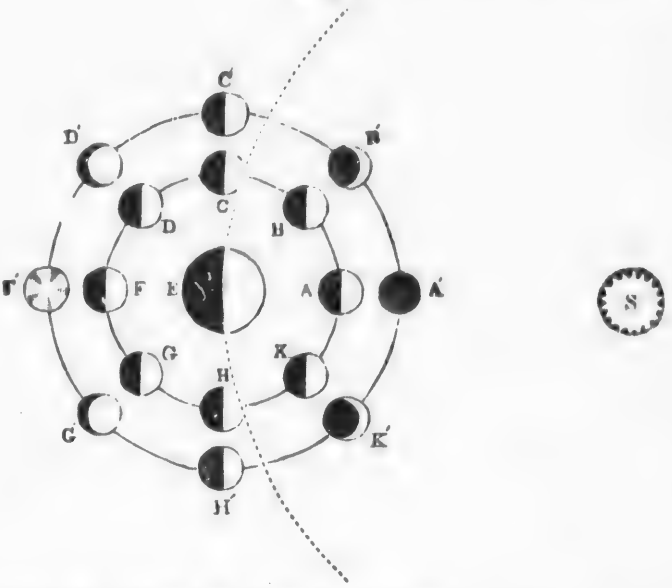
334. The moon's phases are owing to the following causes. She is a dark body in herself, and shines only by reflecting the sun's light; so that only one half of her surface—that which is next the sun—is illumined at a time: and the only parts that can be seen are those parts of the illumined half which are turned towards the observer. But, owing to the moon's motion round the earth, different amounts of the bright half are turned towards the earth at different times, so that she appears of every different magnitude, from full moon till she disappears altogether.

335. The following figure will illustrate the moon's phases, and also those of Mercury and Venus.

Let S represent the sun, E the earth, and A, B, C, D, F, G, H, K, in the inner circle, the moon, revolving round the earth in the direction of the order in which the letters have just been named. Then at A, when the sun and moon are in conjunction, the unenlightened half of the moon is turned towards the earth, as shown at A′ in the outer circle, and the moon is not seen; or, *it is new moon;* or, as sometimes expressed, *the moon*

changes. At B, as is seen by the points where the inner circle cuts the moon, a small part of the enlight-

Fig. 28.



ened side comes into view to the earth; but the greater part of the side turned towards the earth is dark, and the moon appears an illumined crescent, as shown at B′, in the outer circle. At C, half of the enlightened part is turned towards the earth, the moon appears like a semicircle, as at C′ in the outer circle. At F, the enlightened side is turned towards the earth, and the moon appears full, as at F′, being then in opposition. As she continues her course, she gradually presents less and less of her bright side to the earth, successively appearing as at G′, H′, K′, in the outer circle, until she again comes into conjunction, and entirely disappears. By tracing the figure, the phases will be

readily understood. The inner circle shows the illumined and dark parts—the outer circle the appearance presented to the earth.

336. When the moon is in conjunction or opposition (as at A and F, Fig. 28), she is said to be in her **Syzigies**—when midway between these points (as at C and H, Fig. 28), in her **Quadratures** (or quarters). The points in her course between the syzigies and quadratures are called **Octants.**

337. The earth appears to the moon as she does to us, but of about thirteen times the size, and affords her a very considerable degree of light. The light which the earth yields the moon renders the dark parts of the latter faintly visible, a little before and after new moon. At these periods the moon's light, as it appears at the earth, is weakest, and the illumined half of the earth most fully turned towards her. See A, K, and B, Fig. 28. This enlightens the dark part of the moon, and this light reflected back to us, renders these dark parts visible with a dull, grayish light—forming the appearance popularly termed "the old moon in the new moon's arms."

Eclipses and Occultations.

338. When the sun or moon is, in whole or in part, obscured by a shadow which gradually comes over the disc and then glides off, this phenomenon is termed an **eclipse.** Eclipses are of two kinds—eclipses of the sun and eclipses of the moon.

339. When any fixed star or planet is obscured by the moon, or a planet passing between it and the earth, this phenomenon is termed an "occultation."

340. Eclipses occur only when the moon is in or near to her *nodes* (that is, when she is crossing the plane of the ecliptic); because then only the moon, earth, and sun can be in the same straight line, or so nearly so that a part of one can obscure part of another. They also

occur only at new and at full moon; that is, when the moon is in conjunction or in opposition.

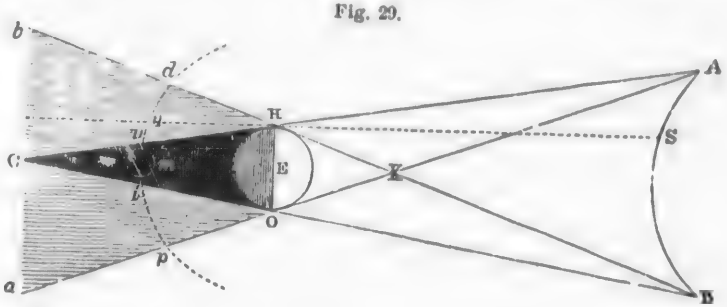
1. Eclipse of the Moon.

341. An eclipse of the moon is caused by the interposition of the earth between the sun and moon, so that the earth prevents the moon from receiving the sun's light, and she is therefore obscured.

342. Hence, an eclipse of the moon takes place only when she is in opposition.

343. The following figure will illustrate an eclipse of the moon.

Fig. 29.



Let A S B represent the surface of the sun, H O the earth, *m* th emoon, *d n i p* the moon's orbit. Then, the sun's rays from A and B, skirting the earth at H and O, will project a conical shadow H C O, within any part of which no rays will be received from the sun. But the parts A and B of the sun also send rays, crossing in K, A O *a*, and B H *b*; and between the line of these rays, and the perfectly dark cone H C O, any object will receive part, but not be illumined by the whole of the sun's rays, part being cut off by the interposed earth. Thus, at *n*, no rays from the sun's surface between S and B will be received, and therefore a less perfect light will be shed at *n*.

344. The perfectly dark space H C O, is called the **umbra** or shade; the surrounding parts *b* H C, *a* O C, the **penumbra** or "almost shade" (*pene*, almost; *umbra*, shade).

345. Now, when the moon is at *d* she will be fully illuminated, receiving rays from the whole of the sun's surface A S B; but whenever she enters the *penumbra*, by crossing the line *b* H, the earth will cut off a portion of the sun's light, and she will receive less and less as she passes onwards towards *v:* after crossing the line H C she is totally eclipsed, and remains so from *v* to *i:* on crossing O C she emerges from the umbra into the penumbra C O *a*, in which she gradually receives light from more of the sun's surface, and becomes more luminous till she passes out of it, and again receives the full light of the sun.

346. The apex of the cone of the umbra extends to a distance of about 774,000 miles beyond the earth; its length, of course, varying according to the earth's distance from the sun.

347. The moon does not disappear from our view completely, even in a total eclipse; this term indicating only that the shadow extends over the whole of the moon's surface next to us. She appears of an earthy brown colour, receiving a few rays by refraction which still enable her to transmit a faint light to us, by which she is rendered visible.

2. Eclipse of the Sun.

348. An eclipse of the sun is produced by the moon passing between the earth and sun, and thus, according to circumstances, cutting off a part or whole of his surface from our view. Hence an eclipse of the sun happens only when the moon is in conjunction, *i.e.*, at new moon. The eclipse may be *total*, when the whole of the sun's disc is obscured; *partial*, when only a part of his surface is obscured; *annular*, when the

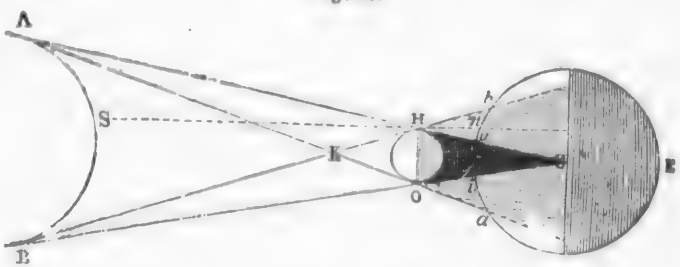
moon cuts off an inner circle, leaving a luminous ring around the part obscured; and *central*, when the place of the observer is in the same straight line with centres of the sun and moon.

349. The distances of the earth, sun, and moon, from each other are the circumstances which determine the nature of the eclipse. The extremity of the cone which forms the moon's umbra falls always near the earth, but sometimes falls short of the earth, sometimes just touches it, sometimes is so long that it could reach a point within the surface, and then there is a spot on the earth where the sun is entirely obscured.

350. As the sun is larger and the moon less than the earth, the earth can never be entirely immersed in the moon's shadow; so that an eclipse of the sun is visible only at a *part* of the hemisphere turned towards him.

351. The following drawing will illustrate total and partial eclipses of the sun.

Fig. 30.



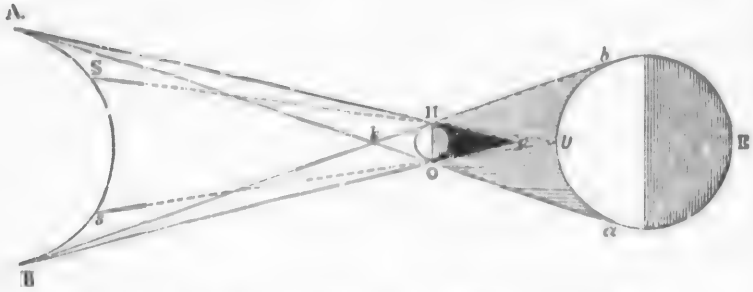
Let A S B be the surface of the sun, H O the moon, *b a* E the earth, H C O the umbra or dark shadow, *b* H C and *a* O C the penumbra, within which only part of the sun's surface is obscured. It is evident that within *v* and *i* there will be a total eclipse; from *b* to *v* and from *i* to *a* a partial eclipse. Thus at *n* the moon will obscure that part of the sun's surface which lies

below the line n H S, so that an observer at n will perceive only the part above that line, or S A, and the extent of the sun's disc eclipsed will be greater according as the place is nearer to v and i, where the *umbra* commences.

352. An annular eclipse of the sun occurs when the apex of the cone of the moon's shadow or umbra falls short of the earth; then there is a margin of the sun's surface left bright all round, while the moon darkens the middle part.

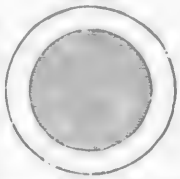
353. This will be illustrated by Fig. 31.

Fig. 31.



Let A S s B, as before, be the surface of the sun, the apex of the conical shadow reaching only to c. It is plain that an observer at v will have part only of the sun's surface cut off from his view—namely, the part within the letters S s—the parts A S and B s will be seen forming a luminous ring all round as shown in Fig. 32.

Fig. 32.



354. There would be an eclipse of the sun every new moon, and of the moon every full moon, if the planes of the moon's orbit and the ecliptic were the same. But as the moon's orbit is inclined upwards of

5° to the ecliptic, at most times of conjunction and opposition she is too far out of the plane of the ecliptic to have any part of her body in the same straight line with the earth and sun, which is necessary to cause an eclipse.

355. But the eclipses do recur at certain regular intervals which have been ascertained with considerable exactness. There is a great lunar cycle of 18 years and 10 days, in which the sun and moon return to the same respective positions, and after which we have the same series of eclipses repeated.

356. Look at the eclipses for 1828 and 1846, and also for 1829 and 1847. They stand as follows.

	1828.		1846.
Sun eclipsed,	April 14.	Sun eclipsed,	April 25.
... ..	Oct. 9.	.. ...	Oct. 20.
	1829.		1847.
Moon eclipsed,	Mar. 20.	Moon eclipsed,	Mar. 31.
Sun ...	April 3.	Sun ...	April 15.
Moon ...	Sept. 13.	Moon ...	Sept. 24.
Sun ..	Sept. 28.	Sun ...	Oct. 9.

"The truth is, that in a great majority of cases (not all) the eclipses do recur after periods of eighteen years, ten or eleven days, and one-third of a day, on the average."

"The period of nineteen years, which was introduced by Meton among the Greeks, and which, under the name of the Metonic cycle, and the cycle of the golden number, has been described in the articles on Easter (see the *Companion* for 1844), is a perfectly distinct thing from the preceding, though sometimes confounded with it. It is founded upon this, that 235 moons last 6939 days, 16½ hours, very nearly. Now 19 years with five leap years is 6940 days, and with four, of course, 6939. The consequence is, that after 19 years, the new and full moons begin to fall on the same days of the months as in the preceding 19 years, or at most one day before or behind. This will be seen by putting down a few of the new and full moons for 1828 and 1847.

	1828.	1847.
Full Moon,	January 2.	January 1.
New ...	January 17.	January 17.
Full ...	February 1.	January 31.
New ...	February 15.	February 15.
Full ...	March 1.	March 2.
New ...	March 15.	March 16.
Full ...	March 31.	March 31.
etc.	etc.	etc."

A. De Morgan, in Companion to the Almanac for 1847.

357. A remarkable phenomenon, hitherto unexplained, was seen during the total eclipse of the sun on the 8th of July 1842. "The moon was like a black patch on the sky, surrounded by a faint whitish light about the eighth of the moon's diameter in breadth, in which three red flames appeared in form like the teeth of a saw."—*Mrs Somerville.*

SECTION VI.

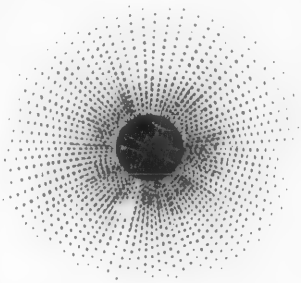
Influence of the Atmosphere on Astronomical Phenomena.

358. The heavenly bodies are rendered visible to us by rays of light which emanate from them and produce impressions of their forms on the eyes of the observer. These rays are somewhat modified in their course before they reach us by passing through the atmosphere.

359. The atmosphere is an aerial fluid, which surrounds the earth on every side. It extends above the surface to a height of about forty-five or fifty miles. It is heavy and dense in the lower regions, but becomes gradually lighter and more rare or expanded as it is higher up; as represented in Fig. 33, where the particles are shown densely crowded below, becoming more open as they are further from the surface. In the figure the extent of the atmosphere in relation to the size of the

earth is greatly exaggerated. The depth of the atmosphere is about *one hundredth* of the distance from the surface of the earth to the centre.

Fig. 33.

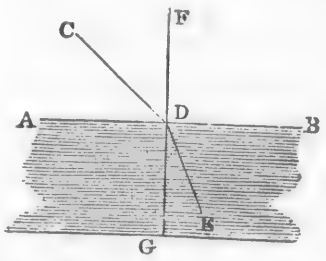


360. The atmosphere is concerned in astronomical phenomena by its power of *refracting* and *reflecting* the rays of light.

361. **Refraction** is that bending of the rays of light which takes place when they pass obliquely from one medium* to another. If a ray of light pass *obliquely* from air to water, from water to air, from surrounding space to our atmosphere, or between strata of different densities of the same medium, it does not continue in the same straight line as before, but is bent, more or less, into another direction, which it preserves so long as it continues in the same medium.

362. Refraction is illustrated by the following figure. Let C D represent a ray of light passing at D from a rare into a dense medium, to the surface of which it is not perpendicular. It will not continue in the direction of C D, but will be bent into the direction D E. If the ray had come from the dense medium in the direction E D, entering the rare medium at D, it would be bent into the direction D C.

Fig. 34.



* Any fluid through which any influence is transmitted is called "a medium" in reference to that influence, as air to light.

Let the line G D F be perpendicular to the surface between the two media; then, it will be evident from the figure that the following is the rule of refraction:

"When the ray passes into a denser medium, it is refracted so as to be nearer to the perpendicular than before; when it passes into a rarer medium, it is refracted so as to pursue its course further from the perpendicular than before."

363. If the ray entered perpendicularly, as in the direction G D or F D, it would not be refracted, but would continue in the same course, G D F, or F D G.

364. Owing to **Refraction**, no heavenly body is seen in its true place unless it be in the zenith. Everywhere else, refraction causes bodies to appear to be higher above the horizon than they really are.

365. This takes place in the following manner: When a ray of light enters the atmosphere obliquely, it is bent down towards the surface of the earth, and as it approaches the ground, it becomes more and more bent in passing from the rarer strata above to the denser medium below. Now the object from which the ray comes appears *in the direction which the ray has at the moment when it strikes the eye.* Accordingly, as refraction in a denser medium bends the ray towards the perpendicular direction, the object will be seen in a direction more perpendicular to the surface than its real one—that is, nearer the zenith, or more elevated above the horizon than it should be.

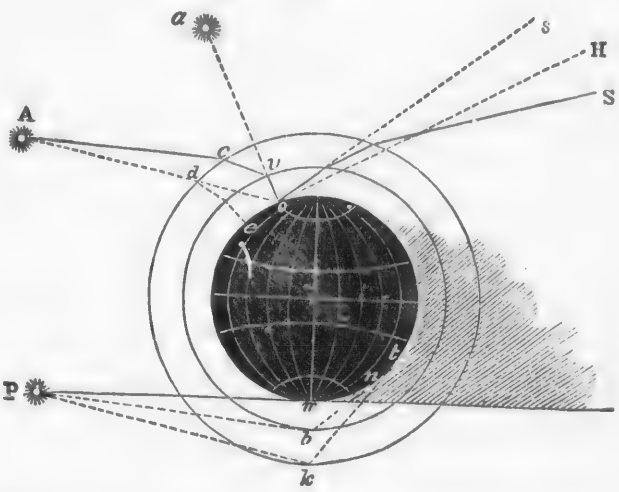
366. Refraction is very slight on the first ray entering the atmosphere, owing to the extreme tenuity of the air in the upper regions; but gradually increases as the ray approaches the earth, the strata of air becoming more and more dense. It is affected by the air's temperature and pressure, which must be taken into account by the astronomer.

367. As the rays from a celestial object in the zenith enter the atmosphere perpendicularly, there can be no

refraction of its rays, and it will be seen in its true place. But, from every other position, the rays will enter the atmosphere obliquely, be refracted, and therefore represent it too elevated.

368. The following figure illustrates atmospheric refraction. Let *o* represent any point on the earth's

Fig. 35.



surface, and A any star or heavenly body. It is seen at *o* by means of rays of light from it which reach the eye—by those rays from A which enter the atmosphere at *c*. They are refracted to *c v*, and, as the air becomes more dense, to *v o*, which is the direction they have on reaching the surface. Accordingly, the star is seen as if it were in this direction, which represents it not at A, but at *a*.

369 The course of the ray from *c* to *o* should be a curve, as the air becomes gradually and insensibly denser. The rav from A, which would have rendered the object visible at *o* had there been no refraction, viz., A *d*, is refracted down to *e*.

370. Refraction increases as the object is nearer the horizon, as the rays then pass through more of the dense strata of air. At the zenth it is 0° 0′ 0″. At 45° above the horizon it elevates the apparent above the true position of a celestial object about 1′—more correctly 57″. At the horizon it elevates the object so much as 33′, or about half a degree—that is, about as much as the sun's apparent diameter.

371. Refraction, by elevating the position of celestial objects, brings into view bodies actually below the horizon, and which, therefore, could not otherwise be seen. Thus, in Fig. 35, the body S, which is below the horizon H *o* of a spectator at *o*, and would therefore be invisible to him, is brought into view and made to appear above his horizon at *s*.

372. Thus, refraction raises the sun above the horizon at both sunset and sunrise, and by causing him to rise earlier and set later than he otherwise would, lengthens the day. As refraction at the horizon is 33′, and the sun's diameter is about 32′, the sun will have sunk below the horizon when his lower margin appears to us resting on it, just about to dip beneath it.

373. Refraction also distorts the figures of the sun and moon when they are near the horizon, rendering them of an oval form, and flattened at the lower part. This is caused by the very rapid increase of refraction near the horizon, so that the lower margins of these orbs are much more elevated than the upper, which shortens the perpendicular diameter, and gives the figure a somewhat oval shape.

374. The **Reflection** of light signifies the bounding off of rays of light from bodies on which they strike; this takes place in the same manner in which a ball rebounds from any hard surface on which it is thrown, or in which sound and heat are reflected.

375. The atmosphere reflects and disperses in all directions the rays which it receives from the sun. Were there no atmosphere, those bodies only would

be visible to us which are in the direct rays of the sun, and thus receive light, which they would transmit to us and render us sensible of their presence. But, by the reflective power of the atmosphere, bodies have light thrown upon them, though out of the direct course of the sun's rays; and thus, as the atmosphere is everywhere present, they receive light in whatever position, which they in turn reflect to us, and thus render themselves visible.

Twilight.

376. **Twilight** is the faint and gradually diminishing light which we enjoy for a considerable time after the sun has fairly sunk below the horizon; and we are indebted for twilight to the reflective power of the air. Those portions of air which are a little nearer to the sun than any place at which the sun has just set, will reflect down to that place (as well as to the parts which have had the sun still longer below the horizon) a part of the light which they receive; accordingly that place will, for a little after sunset, receive an inferior degree of light reflected from the air—or *twilight*. And, as it will receive reflected light from a less body of air as the sun sinks lower below the horizon of a place, its twilight will diminish gradually till total darkness supervenes.

377. This is illustrated by the lower part of the above figure, 35. Let the sun, P, be on the horizon of the place *m*, having completely set to *n* and *t*. These places, *n* and *t*, would be completely dark were there no atmosphere. But though the sun is far below the horizon of *t*, it will receive a small portion of light reflected from the upper air at *k*, and from all the air higher than the shaded part and beyond the line *k t*. The earth at *n*, not so far out of the sun's rays, will receive reflected light from a much larger portion of the atmosphere, viz., from *b*, lower down, and from all the air without the shaded part and beyond the line *b n*.

378. Twilight continues while the sun is less than 18° below the horizon. Hence, some parts of the earth have continual twilight at certain periods of the year, as at London, from May 22 to July 21. The *real*, or astronomical twilight, is of much longer duration than what is popularly regarded as twilight; for it commences immediately after the sun is below the horizon, when there is still good daylight, and continues for some time after it is apparently dark. There is long twilight around the poles, which illumines these desolate regions when the day is short, or the sun below the horizon for days or months together.

379. There is shorter twilight the nearer the place is to the equator—there the astronomical twilight continues for about 1 hour 12 minutes. The rapid rotation of the parts about the equator, and the great distance from the axis, bring very soon a considerable convexity between the sun and the spectator, so that the period of reflection is cut short. Hence the diminishing duration of twilight as we approach the equator, where it is often said that there is *no twilight*. This is incorrect; the twilight is merely very short.

380. The *dawn*, or light before the sun has actually risen above the horizon, is due to the same cause and subject to the same general rules as the twilight in the evening. Owing to the different condition of the atmosphere as to vapours, which abound after sunset, twilight is a little longer than dawn.

PART III.

THE SOLAR SYSTEM.

381. The solar system (or *our* system) consists of certain of the heavenly bodies, which are connected with the sun, and form a system by themselves, apart from the others. The word "solar" is derived from "Sol," the Latin word for "the Sun."

382. The solar system is composed of the **Sun**, the **Planets** with their **Satellites**, the **Comets**, **Aerolites** (or meteoric asteroids), and, probably, a thin fluid or **Ether** occupying the intermediate spaces, and spreading out into space far beyond the limits of our system.

383. The **Planets** are those stars which do not remain in one spot, but are found to change their positions in the heavens. They are therefore termed *planets*, from the Greek word πλανήτης, signifying a *wanderer*. They are so named in contradistinction to the fixed stars, which preserve their relative positions comparatively unchanged. Five are visible to the naked eye.—See par. 45. The earth also is a planet, and must appear as a star to those who live on the neighbouring planets, as Venus and Mars. **A Comet** is a kind of irregular and less substantial planet.

384. The connexion between these bodies is this: The planets and comets revolve round the sun, receive light and heat from him, and are preserved, mainly by his action, in their proper paths around him. The **Satellites** are lesser or secondary planets, which revolve round some of the larger planets, are carried with them round the sun, and also receive light and heat from that luminary. The moon is a satellite to the earth.

385. The heavenly bodies which compose the solar

system have each two *principal* motions, one round the sun, termed its *revolution* or *orbitual motion;* another, turning on itself, round an imaginary line called the axis, passing through it, termed its *rotation.* Some, as the earth, have other motions; see *Precession.* In addition to these, the sun himself, with all the planets in his train, is rapidly advancing through space.—See pars. 502 and 707.

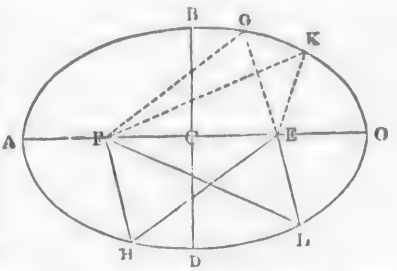
SECTION I.

Definitions.

386. An **Ellipse,** or **Oval,** is a curved line, such, that the sum of two straight lines, drawn from two points within to any point in the curve, shall always be the same. These two points are termed the **Foci** of the ellipse.

Fig. 36 represents an ellipse. F and E are its foci, and if G, K, L, be any points in its circumference, then G F and G E together will be of the same length as K F and K E together, or L F and L E together.

Fig. 36



387. An ellipse may easily be drawn in the following manner:—Fix two pins in the paper at the points selected for the foci, as at F and E; and pass a thread having its ends tied together (an endless thread) round them; the thread being longer or shorter, according to the size and form of ellipse desired. Then stretch the thread out by the pencil, giving the thread the form F G E F, or F K E F, as may be, and then carry the pencil round the foci, pressing it gently but firmly on the paper, and keeping the thread equally stretched till the pencil has completed its circuit. The pencil will then have formed an oval or ellipse upon the paper.

388. The *ellipse* is one of the figures called *conic sections*, formed by the section or cutting of a cone by a plane. If the plane cut the cone *parallel to the base*, the section will be a **circle**: *obliquely through both sides*, the section will be an **ellipse**: *parallel to the side*, the section will be a **parabola**; and when the cutting plane *makes a greater angle with the base than the side of the cone*, the section is a **hyperbola**. If the plane pass through the vertex, the section will be a **triangle**.

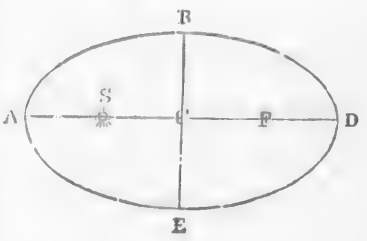
389. The **Major Axis** of an ellipse is the straight line drawn through the foci, and terminated both ways by the circumference, as A O. The middle point of this line, C, is the **Centre** of the ellipse. The minor axis of the ellipse is the straight line through the centre at right angles to the **Major Axis**, as B D.

390. A **Tangent** (or touching line) to a curve is a straight line which touches the curve, and being produced both ways, does not cut it, that is, does not go into it. In Fig. 8, D K and P H Q are tangents. (A tangent of a circle is at right angles to the diameter drawn through the point of contact.—There may be tangents to other curve lines as well as to circles.)

391. The path or course in which any of the heavenly bodies moves is termed its *orbit;* from the Latin *orbita*. The orbits of the planets, satellites, and many of the comets, are *ellipses*, the sun, or planet round which a satellite revolves, being in one of the foci; as at S in Fig. 37 below.

392. The **Linear Eccentricity** (from *ex*, out of, and *centrum*, the centre) of a planet's orbit is the distance from the centre of the ellipse in which it revolves to the body round which it revolves. In the adjoining figure, if A B D E represent the orbit of a planet or satellite, if C be its

Fig. 37.



centre, and S the sun (or primary planet), then the distance C S will be the linear eccentricity.

393. The *eccentricity* is more usually taken to mean the proportion which the lineal eccentricity bears to the semi-axis major, *i.e.*, the proportion of C S to A C. Thus, if C S were ¼ of A C, we should say that the eccentricity is ¼ or ·25.

394. As the minor axis (B E, Fig. 37) of an ellipse increases, or the major axis decreases, the foci (S and F) draw nearer to the centre and to each other; the eccentricity (C S or C F) lessens; and the figure approaches to that of the circle. When the major and minor axes are equal, the foci and centre coincide, and the figure is a circle.

395. In the case of the planets and satellites the two axes are nearly equal, the eccentricity is small, and the orbits, therefore, are nearly circular. In the orbits of the comets, the minor axis is considerably less than the major axis, the eccentricity great, and the ellipse elongated.

396. A planet's *greatest distance* from the sun is when it is at the extremity of the major axis farthest from that luminary—its *least distance* when at the other end, that nearest the sun. And the difference between the least and greatest distances will be twice the eccentricity. In Fig. 37 above, if S represent the sun, a planet is farther from the sun at D than at A by S F, *i.e.*, C S and C F, or twice the eccentricity. The *mean distance* of the planet from the sun is the half of the major axis, or, the *semi-axis major*, as C A or C D. Observe the sun, S, is not in the centre of the ellipse.

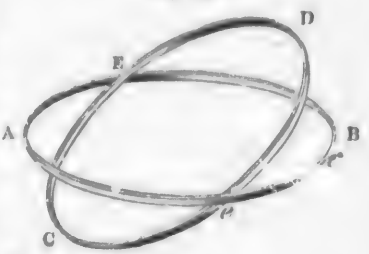
397. These two points in a planet's orbit, where it is at its greatest and least distances from the sun, are termed its **Apsides**, from the Greek word ἁψις (apsis), the curvature or bend of an arch. The point furthest from the sun (D, Fig. 37) is termed the **Aphelion**: the point nearest the sun, **Perihelion** (A, Fig. 37):—from the Greek words ἥλιος (helios), the sun, ἀπὸ (apo), from, and περι (peri), around or near.

398. **Apogee** is the point in the moon's orbit where it is farthest from the earth; **Perigee**, the point where it is nearest to the earth:—from γη (ge), the earth, ἀπὸ (apo), and περι (peri).

399. The **Ecliptic** is that great circle of the starry sphere in which the sun's centre appears to move during the year; or, *the path through the heavens which the earth would appear to describe, if seen from the sun* (par. 104).

400. The **Nodes** of a planet are the two points where its orbit cuts the plane of the ecliptic. In Fig. 38, if E B *e* A represent the plane of the ecliptic, and E D *e* C the orbit of any planet, the points E and *e* are the nodes. The line joining the nodes is called the *line of the nodes;* a line from E to *e* would be the line of the nodes.

Fig. 38.



401. The point at which a planet crosses to the *north* of the plane of the ecliptic is termed its *ascending node;* the point at which it crosses to the *south* of the plane of the ecliptic, its *descending node.*

The term *node* is from the Latin *nodus*, applied to signify an intersection.

402. It must be observed of the above figure that E B *e* A is meant to represent the *plane* of the ecliptic, not the ecliptic itself, which may be far *beyond*, or *within* E B *e* A. If the curves in the figures above represented both the actual orbits of planets, there would be danger of collision, as was apprehended of the earth and the comet of 1832, which actually did pass through a point in the earth's orbit, fortunately, however, *a month before* the earth in its annual revolution reached that point in space, the two bodies being then about fifty-five millions of miles from each other.

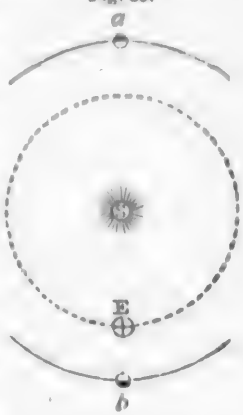
403. The **inferior** planets are those which are nearer to the sun than the earth, as Venus and Mercury.—The

superior planets are those which are further from the sun than the earth, as Mars, Jupiter, Saturn, etc.

404. When two celestial objects are on the same meridian they are said to be in **conjunction**; when on the opposite meridians, they are said to be in **opposition.**

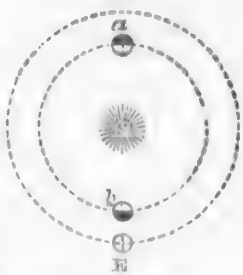
405. For example, when a superior planet, as Mars, is on the same meridian as the sun, the sun being between the earth and the planet, which appears in the same part of the heavens as the sun, and on the same celestial meridian, the sun and planet are said to be in **conjunction.** Thus, in Fig. 39, if E be the earth, and *a* Mars, the sun and Mars would be said to be in **conjunction.** When the earth is between the sun and planet, so that they appear on the opposite parts of the heavens, that planet and the sun are said to be in **opposition,** as at *b* in the same figure.

Fig. 39.



406. In the case of the inferior planets, when the planet is between the earth and sun, it is said to be in **inferior conjunction**; when the sun is between the earth and planet, it is said to be in **superior conjunction.** In Fig. 40, if E be the earth, and *a*, *b*, different positions of an inferior planet, it is in *inferior conjunction* at *b*, in *superior conjunction* at *a*.

Fig. 40.



407. Hence, when a planet is in conjunction, it rises and sets about the same time as the sun. When it is in opposition, it sets when the sun rises, and rises when the sun sets.

408. The **disc** of a heavenly body is the face, or apparently broad flat surface which it presents to the eye.

409. The **phases** of the moon or a planet are the different appearances it presents, according as more or less of its illuminated surface is turned towards the earth, from the Greek word φασις (phasis), the appearance presented by a body.

410. The term **transit** is usually applied to the passing of Mercury or Venus between the earth and sun, appearing like a black spot on his disc. It is from the Latin *transitus*, signifying a passage or going over.

411. **Occultation** (disappearing or being hid) is the eclipse of a star or planet by the interposition of the moon or some planet, which intercepts our view of it.

412. Motion is said to be **uniform** when its rate remains the same; **accelerated**, when it becomes quicker every moment; **retarded**, when it becomes every moment slower. The **mean motion** of a planet is the rate at which it would go if it moved uniformly, still describing the same distance in the same time.

413. A **spheroid** is a figure like a sphere, but having its surface flattened at the two extremities of one of its diameters, like an orange. That diameter is the shortest, and the diameter at right angles to it is the longest diameter of the spheroid. It is sometimes termed an *oblate* spheroid, in contradistinction to a figure like an egg, called a *prolate* spheroid.

414. A **pendulum** is any body suspended at a fixed point, about which it swings backwards and forwards. It performs its oscillations (vibrations) in equal times, however different in length they may be, so long as the pendulum continues of the same length, or the force which causes it to move remains the same. But if the pendulum be made shorter, or the moving force be greater, it will move more quickly, and *vice versa*. As it is the force of gravity which causes its oscillations,

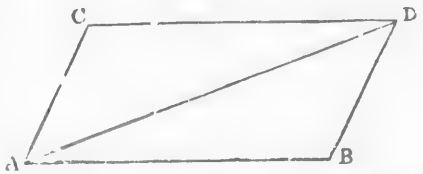
these are more rapid the stronger the action of that force is; and accordingly it has been used as a measure of the strength of gravity. The vibrations of the pendulum are more rapid as the rod is shorter (the time of each vibration being in proportion to the square root of the length of the rod). At the latitude of London, 51° 30′ 47·59″ north, the length of the pendulum which vibrates in one second is 39·138 (about $39\frac{1}{8}$) inches. From the isochronism (equal times) of its vibrations it is used for measuring time.

415. The term force is applied to express anything that produces, or prevents, or changes motion, or tends to produce, prevent, or change motion.

416. A body actuated by a single force would, if that force were sufficient to impart motion to it, move on for ever in a *straight line* in the direction of the force.

417. When *two* forces act upon a body at the same moment, it moves in a certain direction, which is found as follows:—Let the forces be represented by two straight lines meeting in a point, whose directions represent the directions in which the forces act, and whose lengths represent the comparative intensities of the forces: complete a parallelogram having these two lines for sides. The diagonal drawn from the point where the lines meet will show the direction in which the body will move, and the force with which it will be impelled. If, in the following figure, the lines A B and A C represent the directions and comparative strengths of two forces acting on a body at A, so that the force A C, acting alone, would carry it to C in the same time in which the force A B, acting alone, would carry it to B, the body A will

Fig. 41.



arrive in that time at D, the other extremity of the diagonal, drawn from A, of the parallelogram A C D B, of which A B and A C are sides.

418. The finding the direction in which two or more forces impel a body is termed the "*Composition of Motion.*"

419. The direction which the body takes always inclines towards the direction of the greater force. Thus, in the above figure, the angle D A B is less than D A C, A B being greater than A C, and A D evidently lies nearer to A B than to A C. A single force which produces the same effect as two or more other forces is called their *resultant.*

420. **Centre of Gravity.**—There is a certain point in every body which bears such a relation to it, that the same effects would ensue from its gravity (weight) if a single force, *equal to its weight* and in *the same direction* (vertically downwards), acted upon the body at that point, the rest of it being then supposed to be without weight. Such a point in a body is called its **centre of gravity.** It is in the middle of a straight rod or bar, in the centre of a circular plate of any material, and in the centre of a sphere or spheroid, supposing these to be of uniform density at every part. As any number of forces acting on a body may be replaced by a single force called their *resultant*, so a body may be considered as an assemblage of separate particles rigidly connected, the gravity or *weight* of each particle is a *force* acting upon it, and the centre of gravity of the body is the point through which, in whatever position it might be placed, the resultant of the forces of all its separate particles would pass. Hence, all the parts exactly balance each other about that point.

421. Two or more bodies taken together may have a *common centre of gravity.* The centre of gravity of two bodies is found by joining their centres of gravity, and dividing the joining line so that the weight of the first is to the weight of the second, as the distance of the centre of gravity of the second from the point of division of the joining line, is to the distance of the

centre of gravity of the first from that point. Then, by a similar method, the centre common to that centre of gravity, and the centre of gravity of a third body may be found, and so on.

SECTION II.

Forces Acting Throughout the Solar System.

422. The heavenly bodies are found to move in *curved lines:* they must, therefore, be acted upon by more than one force. (416.)

423. The orbitual motions of the planets, satellites, and comets, are caused by the concurrent action of at least two forces;—*first*, A **projectile, tangential,** or **centrifugal** force; *second*, An **attractive, central,** or **centripetal** force.

1. Projectile Force.

424. Any body thrown or projected forward, is called a *projectile*, as a stone from the hand or a sling, an arrow, a musket or cannon ball; and any force which tends to impel a body in such a manner, is called a *projectile force.* It is considered that, at some time, the planets, satellites, and comets must have received some such impulse, which set them in motion, and which, combined with the attractive force, preserves them in motion in that course which they now pursue.

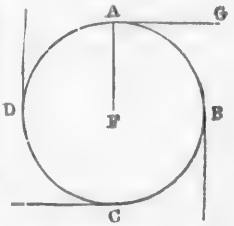
425. As, by the inertia of matter, a body tends to continue in the state in which it is, whether that be one of rest or of motion, the heavenly bodies do not require new impulses to preserve their motion. That motion, once imparted, continues uninterruptedly till it is weakened or destroyed by the opposing action of some other force.—"The force by which the body is projected

is one which we suppose to be necessary at some past time to account for the planet's motion, but which acts no more. The planets *are in motion*, and it is of no consequence to our inquiry how they received this motion; but it is convenient, for the purposes of calculation, to suppose that at some time they received an impulse of the same kind as that which a stone receives when thrown from the hand; and this is the whole meaning of the term 'projectile force.'"—*Gravitation*, by AIRY.

426. The projectile force, acting alone, would throw the revolving body out of its orbit, and cause it to move on for ever in a straight line. The direction of this line would be a tangent (see par. 390, and Fig. 8, p. 21) to the orbit at that point where the attractive force ceased and the projectile force alone acted on the body: or, would be in the direction which the planet had at the moment of quitting the orbit.

427. Thus, in the adjoining figure, let the circle A B C D represent the course of a body moving round in the direction from A towards B, B towards C, and so on, and at the same time drawn by a central force towards F. If, when at A, the central force were to cease, the projectile force would cause the body to break off from its course and proceed on in the straight line A G, which would be a tangent to the circle at A. At B, C, or D, were the projectile force alone acting, the body would proceed in the lines drawn from these points in the figure. And in the whole course of its revolution, the body has a tendency to break off in this manner—in a tangent to the curve at the point where it is when the central force ceases.

Fig. 42.



428. This force, therefore, is termed *projectile*, as it tends to throw the body out of its orbit, and resembles the force with which any projectile is impelled from the surface of the earth. It is termed *tangential*, as it tends to throw the body off in a tangential direction, and *centrifugal*, as it tends to impel it *from* the centre round which it has been revolving.

429. The existence of the projectile force is inferred from the

orbitual motions of the planets; but no particulars as to its source or nature have been ascertained. It has been calculated that if the earth received its motions of rotation and round the sun from a single impulse, that impulse must have passed through a point about twenty-five miles from its centre. An impulse through the centre of gravity of a sphere would cause it to move forwards in a straight line—through any other point, the impulse would cause both rotation and motion in space.

430. This centrifugal force, or tendency of a revolving body to fly off from the circle in which it moves, in the tangential direction, is well illustrated by the projection of the mud which adheres to a carriage wheel, —by the water being thrown out of a mop when it is rapidly whirled,—by the necessity which compels the equestrian galloping in a circular arena to lean inwards when the speed is great, to overcome the tendency of his rapid motion to throw him outwards,—in the manufacture of crown or window glass, in which a knob of glass is made to become a bowl of many forms, gradually spreading out, until it suddenly expands into a broad flat sheet,—in a railway train running off the rails at a curve when the speed is not slackened,—and very strikingly, in the *centrifugal railway.*

2. Attractive Force.

431. This is the force exerted by the central body, on a planet, comet, or satellite revolving round it, by which the latter is preserved in its orbit, and prevented receding from the centre into free space, as it otherwise would do from the action of the projectile force.

432. This power is termed *attractive*, as it tends to draw the planets towards the sun, and bodies generally towards each other, etc.; *central* or *centripetal* (centre-seeking), as it urges them towards the centre round which they revolve; and *radial*, as it acts in the direction of the radius.

433. The attractive force, acting alone, would draw the revolving bodies *inwards* from their orbits in the

direction of the radius, and precipitate the planets and comets on the surface of the sun, and satellites on the primary planet round which they revolve.

Thus, if A, Fig. 42, be a body revolving in the orbit A B C D, and the projectile force were suspended at A, the planet would move to the central body in the direction A F.

434. It was demonstrated by Sir Isaac Newton that a particle of matter placed on the outer surface of a hollow sphere is attracted by it in the same manner as if the whole matter of the hollow sphere were collected into one particle in its centre. As a solid sphere may be regarded as made up of an infinite number of concentric hollow spheres, of each of which the above would be true; the same must be the case with the solid sphere: it must attract a particle at its surface in the same manner as if its whole mass were in its centre. The heavenly bodies are so nearly spheres, and so distant, that they act upon each other as if each were gathered into one very dense particle at its centre of gravity, possessing the aggregate force of the mass. And the true centre of the planetary motions is not the sun's centre, but the centre of gravity of the solar system (421). This point, however, owing to the enormous mass of the sun compared with that of all the planets, etc., is only twenty-five miles distant from his actual centre. In like manner, the earth and moon move round their common centre of gravity, and that is to be regarded as the point which is attracted by and moves round the sun.

435. *The force of attraction is measured by the space through which it draws a body in one second of time after the body is set at liberty.* If the attractive force be great, it will cause the body to move through a greater space than a smaller attractive force would do; and this is the best measure of gravity, as it applies equally to all bodies, irrespective of their size or density. For, it has been found (first by the celebrated experiments of Galileo) that, disregarding the resistance of the air, large and small bodies, dense and light bodies, fall through the same space in the same time. And if the planets, satellites, and comets were at equal distances from the sun, and left solely to his action, they would all reach his surface in the same time. The force of the

earth's attraction, or force of gravity, is such as to cause a body within any moderate distance of the earth's surface to fall 16 feet (correctly, $16\frac{1}{12}$ feet) in a second, imparting to it at the end of the second a velocity of 32 feet per second, and continuing its action at the same rate; while the effect of the previous impulses remain, and thus the rate of descent becomes rapidly accelerated. The pendulum, when drawn out of the vertical line and left to itself, is, in a manner, a falling body; and the time in which it descends affords a measure of the earth's attraction—the force which causes its oscillation (a descent and ascent).

436. The attractive force prevailing through the solar system seems to be the same as that well-known power, distinguished on our planet as the **force of gravity**, which causes bodies to fall to the ground when left unsupported in the air, and which makes them exert on bodies beneath them the pressure which we term **weight**. Newton first showed that the force which retains the moon in her orbit is the same which causes heavy bodies to fall to the ground. The sun in like manner attracts the planets and comets; the moon in her turn attracts the earth, and thus moves the waters; and each body is the source of an attractive energy spreading through space, and more or less acting on every other.

437. When spoken of with respect to its action throughout the solar system, it is termed attraction of gravitation, or, simply, **gravitation.**

438. Three things may be noted with respect to **gravitation.** 1. That it acts in all directions, spreading its influence out from a body like rays of light from a luminous object. 2. That its force is in direct* proportion to the quantity of matter (*i. e.*, to the **mass**) in the attracting body. 3. That its force is in inverse* proportion to the square of the distance.

* When one thing alters in a certain way in the same proportion in

439. That gravitation acts in all directions is shown by a plummet suspended near the top of a high precipice leaning towards the rock, — by bodies tending towards the earth *on every side*,—by the action of the moon in raising the waters of the ocean, and forming the tides,—by the mutual action of the sun, planets, and satellites,—and by Mr Cavendish's celebrated experiments, in which small leaden balls were supported on the ends of a rod which was suspended at the middle by a slender wire; and when large leaden balls were brought near to them, it was found that the wire was immediately twisted by the motion of the balls.

440. On the earth's surface gravitation acts in one predominating direction—namely, towards the centre of the earth—giving bodies that strong and invariable tendency downwards called **Gravity.** This is not owing to any difference in *nature* between the mass of the earth and bodies upon it—but to the circumstance of that mass being so very great compared with that of any body on its surface, that all lateral attractions are overpowered by the overwhelming force of the immense mass under our feet. Also, lateral attractions neutralize each other, while the force of the earth's attraction is not neutralized by any opposite force equally near.

441. That the force of gravitation is in inverse proportion to the square of the distance, is a mathematical deduction from the elliptic form of the orbits of the planets, with the sun in one focus; following, therefore, from the second law of **Kepler** (see par. 454).

442. That gravitation has force in *inverse proportion* to *the square of the distance*, signifies, that the attraction of one body for another, when placed at different distances (other things remaining the same), is as much *greater* as the square of the distance is *less*, and as

which another alters in the same way, this is termed *direct* proportion. Thus, in the above instance, if the quantity of matter *diminishes*, the force of attraction *diminishes* as much. When one thing alters in a certain way in the same proportion in which another alters in the opposite way, this is *inverse* proportion. Thus, in the above instance, if the square of the distance between two bodies *diminishes*, the force of attraction between them *increases* as much as the square of the distance has diminished.

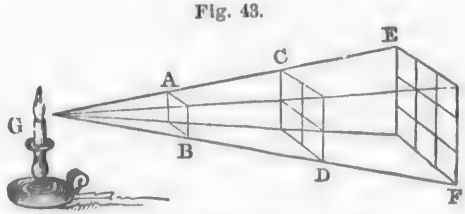
much *less* as the square of the distance is *greater*. This is illustrated by the following table, where the first two columns represent different distances,—the next two, the proportionate forces of attraction at these distances, in squares,—and the last two, the value of these squares expressed in numbers.

Attraction		Attraction								
at 1	*is to*	at 2	*as*	2^2	:	1^2,	*as*	4	:	1
2	... ...	5	...	5^2	:	2^2	...	25	:	4
2	... ...	1	...	1^2	:	2^2	...	1	:	4
3	... ...	7	...	7^2	:	3^2	...	49	:	9

Thus, if a body be first at a distance of 1, and then of 2 from another body, the proportionate forces of attraction exerted by it on the latter body will be 1 at the distance of 2, 4 at the distance of 1. If they be at distances of 3 and 7, the attraction at 3 will be 49, while that at 7 will be 9.

443. The diminution in the above proportion of an influence radiating from a central point, may be illustrated by the following figure. Let G represent any luminous body, A B, C D,

Fig. 43.



and E F, boards at the same successive distances as A B from G, A B being at 1, C D at 2, E F at 3. The same quantity of light which spreads over A B will, at C D, *twice* the distance, spread over *four* times the surface; at E F, *thrice* the distance, spread over *nine* times the surface. But the same amount of light, when diffused over four times the space, will only have *one-fourth* the intensity—over *nine* times the space, one-ninth of the intensity. Hence the light at 1 *is to* that at 3 *as* $3^2 : 1^2$, as 9 : 1, or as 1 : $\frac{1}{9}$;—that is, inversely as the squares of the distances.

444. It is known that this universally diffused power extends to the utmost limits of the solar system. We have reason to believe, from the phenomena of binary stars, that it also prevails among the fixed stars. And, there is reason to suppose, that its various forms, as exhibited on our globe,—gravity, cohesion, chemical attraction, electric and magnetic attraction,—are merely varieties of one fundamental power.

445. Few things are more striking than that invisible and mysterious connexion which subsists between the separate particles or masses of matter—drawing or binding them towards each other—acting with such enormous power, and at such immense distances as in the central force which, spreading from the sun in all directions, preserves the planets in their orbits, at distances of thousands of millions of miles, and perhaps preserves *systems* in their proper positions, at distances measured in millions of millions of miles—exhibited also between the planets in the disturbing action they produce on each other or on the comets—drawing a stone or drop of rain to the ground—causing the rain or dew drops to form into globules like suns and planets in miniature—binding the particles of iron to each other with the force which enables it to bear such prodigious strains—aiding in producing the singular phenomena of electricity and magnetism—and, lastly, in its action between different bodies, giving rise to the phenomena of chemistry, and creating the innumerable and ever-varying combinations which surround us on every side.

446. It has been inferred from astronomical phenomena, that the action of gravitation is either instantaneous, or that its velocity is at least *fifty million times* greater than that of light; and also, that it penetrates freely through the densest bodies and acts on another body, without any diminution of its energy.

447. Besides gravitation, the force of **Heat** spreads throughout the solar system; and we know that, on our planet at least, and in the comets at certain times, it gives rise to motions among the particles which occasion various important and interesting phenomena. Although we can ascertain little of its operation in other parts of the solar system, it is not probable that an influence excited by the sun's rays, and capable of effects so great on our earth, will be without action on other bodies equally exposed to the effects of whatever emanates from the sun. Accordingly, the force of heat, as a probable element in astronomical changes, must not be overlooked in enumerating the forces of the universe.—**Heat, Light,** and **Gravitation** link us with far

distant worlds; and perhaps there are still other influences, so fine and inappreciable as to have hitherto escaped our notice, operating silently upon us, and binding together in one connected chain the most remote parts of creation.

448. The solar influences which give rise to heat and light, obey the same law with respect to their strength at different distances, as gravitation, *i. e.*, inverse proportion to the square of the distance. Thus, the distance of Mercury being 36 millions of miles, and that of the Earth 92 millions of miles, the following proportion will hold:—

Sun's influence at Earth : Sun's influence at Mercury, *inversely*, as $92^2 : 36^2$, *directly*, as, $36^2 : 92^2$; as $1250 : 8481$, or as $1 : 6\frac{3}{4}$.

Thus, the sun's influence at Mercury is nearly seven times what it is at the earth.

449. But it must not be inferred from this, that the temperature at the different planets is in exact proportion to the sun's influence; for the temperature is dependent not only on the amount of the heating agent, but on many circumstances connected with the body acted on. This is illustrated on our own planet, where, owing to the increasing rarity of the air, as the elevation is greater, the solar rays produce less effect in proportion as the height above the level of the sea increases: so that, at any latitude, the low grounds are warmer than the elevated districts and mountains, which are actually nearer to the sun.

SECTION III.

Orbitual Motions of the Planets, Satellites, and Comets.

450. By observation of the changes in position of the planets, satellites, and comets, and by computation

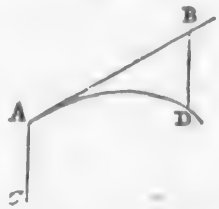
from their observed movements, it has been ascertained that they move constantly and regularly in certain orbits—the planets and comets round the sun, the satellites round some planet. And these motions are explained by the supposition of a *projectile impulse* originally imparted to each body, and a *central or attractive force* continually acting on it.

451. Suppose that a body is projected in a direction *transverse to*, or *crossing* the direction in which the force of attraction draws it, how will it move?

"The simplest instance of this motion that we can imagine is the motion of a stone when it is thrown from the hand in a horizontal direction, or in a direction nearly horizontal. We all know that the stone soon falls to the ground; and if we observe its motion with the least attention, we see that it does not move in a straight line. It begins to move in the direction in which it is thrown; but this direction is speedily changed; it continues to change gradually and constantly, and the stone strikes the ground, moving at that time in a direction much inclined to the original direction. The most powerful effrot that we can make, even when we use artificial means (as in producing the motion of a bomb or cannon-ball), is not sufficient to prevent the body from falling at last. This experiment, therefore, will not enable us immediately to judge what will become of a body (as a planet) which is put in motion at a great distance from another body, which attracts it (as the sun); but it will assist us much in judging generally what is the nature of motion when a body is projected in a direction transverse to the direction in which the force acts on it.

"It appears then that the general nature of the motion is this: the body describes a curved path, of which the first part has the same direction as the line in which it is projected. The circumstances of the motion of a stone may be calculated with the utmost accuracy from the following rule, called the second law of motion (the accuracy of which has been established by many simple experiments, and many inferences from complicated motion). If A, Fig. 44, is the point from which the stone was thrown, and A B the direction in which it was thrown; and

Fig. 44.

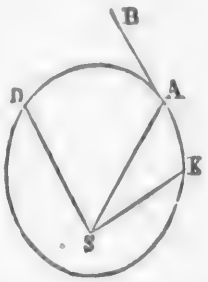


If we wish to know where the stone will be at the end of any particular time (suppose, for instance, three seconds), and if the velocity with which it was thrown would, in three seconds, have carried it to B, supposing gravity not to have acted on it; and if gravity would have made it fall from A to C, supposing it to have been merely dropped from the hand; then, at the end of three seconds, the stone really will be at the point D, which is determined by drawing B D parallel and equal to A C; and it will have reached it by a curved path A D, of which different points can be determined in the same way for different instants of time."—*Airy on Gravitation.*

452. In giving the planets their orbitual motions, these two forces act on the principle of the composition of motion (par. 417). Any curved line may be considered as made up of a number of infinitely small straight lines, which will be the diagonals of a series of parallelograms, whose sides will be lines in the directions of the projectile and attractive forces at each point, and of lengths proportionate to the intensities of these forces. As the directions of the tangent and radius change at every step, the body enters every moment upon a new diagonal, the series of which will form the curve which it describes.

453. "It is demonstrated that if a body (a planet, for instance) is by some force projected from A, Fig. 45, in the direction A B, and if the attraction of the sun, situated at S, begins immediately to act on it, and continues to act on it according to the law we have mentioned (that is, being inversely proportional to the square of its distance from S, and always directed to S); and if no other force whatever but this attraction acts upon the body; then the body will move in one of the following curves—a circle, an ellipse, a parabola, or a hyperbola.

Fig. 45.



"In every case the curve will, at the point A, have

the same direction as the line A B; or (to use the language of mathematicians) A B will be a tangent to the curve at A.

"The curve cannot be a circle unless the line A B is perpendicular to S A, and, moreover, unless the velocity with which the planet is projected is neither greater nor less than one particular velocity determined by the length of S A and the mass of the body S. If it differs little from this particular velocity (either greater or less), the body will move in an ellipse; but if it is much greater, the body will move in a parabola or hyperbola.

"If A B is oblique to S A, and the velocity of projection is small, the body will move in an ellipse; but if the velocity is great, it may move in a parabola or hyperbola, but not in a circle.

"If the body describes a circle, the sun is the centre of the circle.

"If the body describes an ellipse, the sun is not in the centre of the ellipse, but in one focus."—*Airy.*

454. The following general laws, developed by Kepler, are found to prevail throughout the solar system:—

I. *The planets move round the sun in such a manner, that the line drawn from a planet to the sun passes over areas proportional to the times of the motions.*

II. *Each planet describes an* **ellipse**, *having the sun in one of the foci.*

III. *The squares of the periodic times* of the planets are in the same proportion as the cubes of their mean distances from the sun.*

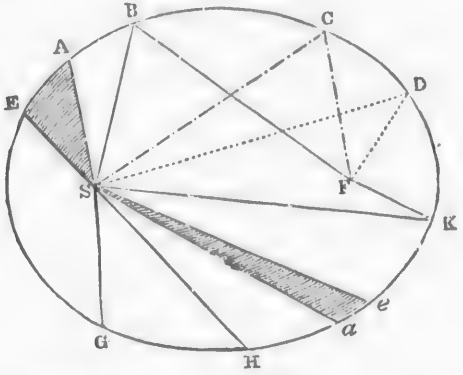
455. The first of **Kepler's Laws** is shortly expressed as follows:—"The radius vector of a planet describes areas proportional to the times."

456. This will be illustrated by the following figure.

* Periodic time—the time occupied by any body in completing one revolution in its orbit.

The *radius vector* of a planet is an imaginary straight line passing from the sun to the planet, supposed to remain fixed at the former, but to follow the planet in its course round that orb, expanding or contracting according as the planet is further from or nearer to the sun.

Fig. 46.



457. In the above figure let S be the sun, and A, E, G, H, *a*, *e*, successive positions of a planet; then S A, S E, S G, S H, S *a*, S *e*, will be the radius vector in these several positions. Now, let it be supposed that the planet moves from A to E, in the same time in which it moves from *a* to *e*: it would then be found that the radius vector, in passing from S A to S E, has traversed the same extent of space as in passing from S *a* to S *e*; that is, that the shaded area S A E is equal to the shaded area S *a e*; or, as expressed above, that the area S A E bears the same proportion to the area S *a e*, as the time of the motion from A to E does to the time of the motion between *a* and *e*; *i.e.*, *that the areas are proportional to the times*—(equal in the instance just given, since the times were supposed equal).

458. Conversely, if the area S E G be equal to the area S G H, the planet will move from E to G

in the same time as from G to H. And any area, S G H, will bear the same proportion to any other area, S H K, as the time in passing from G to H does to the time in passing from H to K.

459. Hence, then, a planet does not move round the sun at a uniform rate; its motion is at one time accelerated, at another retarded.

460. For, as the planet is at different distances from the sun, and its radius vector describes equal areas in equal times, any area, when the planet is near the sun, must be broader than an equal area when the planet is remote: the part of the orbit which bounds the broad area must be longer than that which bounds the narrow one; and as they are both described in the same time, the planet must move faster in that nearest the sun.

461. The velocity of a planet is least when furthest from the sun, becomes accelerated as it comes nearer, is at its highest when the planet is nearest to the sun, and becomes retarded as its distance from the sun increases.

462. The velocity of a planet in different parts of its orbit is in inverse proportion to the square of its distance from the sun.

463. From this law, that the areas described by the radius vector are proportional to the times, the conclusion was drawn by **Newton** that the powers by which the tangential force of the planets is neutralized is directed towards the sun.

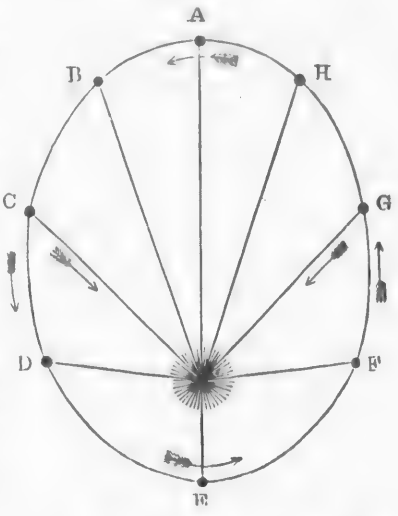
464. The second of **Kepler's Laws** is, that "the orbits of the planets are ellipses, with the sun in one focus."

465. The planets and comets do not fall to the sun when they approach nearer to him, as might be expected, because the tangential force becomes stronger at the same time; and they do not fly from the sun altogether when they recede from him, because while they recede from him the tangential force at the same time diminishes in energy.

466. That this is the case will be illustrated by the following figure. Let this figure represent the orbit of

a planet, A; S being the sun. Let the planet be in its aphelion at A. It is there under the influence of the attractive and projectile forces, whose united operation brings it to B. Being there nearer to the sun, it is more powerfully attracted and drawn still nearer to him; and, as *the attractive and projectile forces are operating nearly in the same direction*, the velocity is increased, the planet proceeding from B to C, a greater distance, in the same time in which it passed over the shorter distance from A to B. At C, being nearer than at B, the attractive energy is further increased, and as this still concurs in direction with the tangential force, the velocity is augmented. This goes on till it comes to its *perihelion* at E, where its velocity is greatest. The great projectile force thus acquired prevents it going still nearer, overcomes the increased attractive force, and causes it, at E, to begin to increase its distance, which it does, step by step, from E towards A, in the reverse order to that by which it had lessened its distance. The attractive force decreases rapidly as the distance increases; but the projectile force also diminishes, *as the sun's attraction is now acting nearly directly against the projectile force*, and it thus lessens its impetus at every step. By this, in progressing from E to F, G, H, the projectile force is so much

Fig. 47



weakened that the attraction of the sun overcomes it in turn, and bends the planet's course towards A, where, when it arrives, the same series of actions commence again.

467. That the attractive and projectile forces act mostly *together* as the planet passes from its aphelion to perihelion, and mostly *against each other* when it is proceeding from perihelion to aphelion, is shown by the directions of the arrows.

468. Were the planets, satellites, and comets under the influence only of their own projectile force, and the attractive force of the central body round which each revolves, they would obey strictly the laws which have just been developed, of motion in ellipses with their radii vectores describing areas proportional to the times. But each is a source of attractive force which more or less influences every other one, and causes disturbances and irregularities in their movements, by which they deviate, often considerably, from truly elliptical orbits. These disturbing forces render the motions of the heavenly bodies exceedingly complicated. The deviation of the planet Uranus from his calculated course led astronomers to suspect some disturbing force, previously unknown; which idea, followed out, led to the great discovery of the planet Neptune, the body whose action on Uranus caused the irregularities in the movements of the latter.

469. The third law of **Kepler** establishes a relation between the distances of the planets from the sun and the periods in which they complete their revolutions round him—namely, that "the squares* of the periods are proportional to the cubes* of the distances."

470. That is, the square of the number of days any

* The square of a number is the number produced by multiplying the number by itself: the cube of a number is the product obtained by multiplying it twice by itself. Thus, 9 is the square of 3, 27 the cube of 3; 4 the square of 2, 8 the cube of 2; 25 the square of 5, 125 the cube of 5.

planet takes to go once round the sun, bears the same proportion to the square of the number of days any other planet takes to complete its revolution round the sun, as the cube of the distance of the first planet from the sun bears to the cube of the distance of the second planet from the sun.

471. Or, in the case of Venus and the earth,

square of		square of		cube of		cube of
224·7	:	365·25	: :	66·6	:	92

The first number expresses the number of days occupied by Venus in her revolution round the sun; the second, the number of days the earth takes to go round the sun; the third number is the distance of Venus from the sun, expressed in millions of miles; the fourth, the distance of the earth from the sun in millions of miles.

SECTION IV.

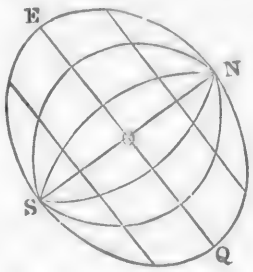
Rotatory Motions and Forms of the Sun, Planets, and Satellites.

472. The sun, planets, and satellites, **rotate**, or turn upon themselves, in regular periods. The time in which this rotation is completed is called the **day** of the revolving body; the imaginary line about which it turns, the **axis**; and the two extremities of this line, the **poles**. They are known to have this rotatory motion by the motion of spots upon their discs; and, by observing the time a spot takes to move through any arc, the time of a complete rotation is ascertained. This motion goes on simultaneously with their motion in space, just as the wheel of a carriage, or a ball in rolling along the ground, rotates while moving onwards.

473. The sun and planets are of a globular form, but not perfect spheres. They are **oblate spheroids**

(413). The flattening is at the poles, or opposite extremities of the axis, and is sometimes termed the "polar compression." This flattening is most remarkable in Jupiter, in which it is so great as to give to that planet a distinctly oval shape. The spheroidal form is shown, considerably exaggerated as regards the sun and planets, in the adjoining figure, where N and S are the poles, and E Q the equatorial diameter.

Fig. 48.



474. The spheroidal form of the sun and planets is most probably caused by their rotatory motion; which has a tendency to produce a flattening at the poles and bulging out at the equatorial regions, even though they had at first been formed perfectly spherical: and their having this form affords a presumption in favour of their having a rotatory motion. A fluid mass of uniform density, the particles of which mutually attract each other, will take the form of a sphere *if at rest*, but will become spheroidal *if it rotates*.

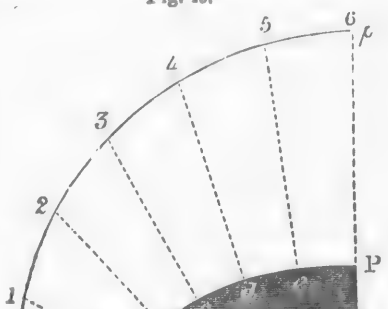
475. That the earth is of a spheroidal form is proved by two circumstances; the slower vibration of the pendulum as the place is nearer the equator, and the increase in length of the degree of latitude as the place is farther from the equator.

476. The rapidity of descent of a falling body is the measure of the force of gravity: the pendulum is such a body; and as it moves (*i. e.*, falls) more slowly the nearer it is to the equator, we infer that the force of gravity diminishes towards the equator; and as the diminution in the rate of movement of the pendulum is greater than can be accounted for by other causes (heat and centrifugal force), part is attributed to the spheroidal form, which must lessen the force of gravity

of the parts near the equator, by placing them at a greater distance from the centre.*

477. But the spheroidal form of our earth is still more clearly proved by the length of the degree of latitude, which is not everywhere the same, but increases slightly towards the poles. Our means of measuring the length of a degree of latitude consist in measuring a degree of an hour-circle in the starry sphere, and finding the distance we must go north or south on the earth, to cause any star to rise or sink one degree in the heavens. It is found that a greater distance is required to effect this the nearer we are to the poles; this is exactly what would take place on a spheroid; and the degree of difference affords a means of estimating the degree of spheroidicity. This may be illustrated by the adjoining figure. Let P Q represent the earth's surface from one pole to the equator, and *p q* the corresponding arc of the heavens, *p* being the pole of the heavens and *q* the equinoctial, 90° distant from the pole. Let the arc *p q* be divided by the points 1, 2, 3, 4, 5 into six equal arcs, which may represent degrees of declination (being in fact arcs of 15° each). Then, the places on the earth at which these points (1, 2, 3, 4, 5) are vertical, would be the corresponding degrees of latitude on the earth. But it

Fig. 49.



* As mentioned in par. 414, the pendulum vibrates more slowly as it is longer. Now, heat expands or lengthens a pendulum rod; so that, from this cause alone, a pendulum must move more slowly in the warm regions of the torrid zone than in higher latitudes.

is evident from the figure, in which the lines *a* 1, *b* 2, *c* 3, *d* 4, etc., are perpendicular to the earth's surface, that the distance between the two adjoining points increases as we pass from the equator to the poles; or that a degree of latitude is longer in proportion as the distance from the equator increases. Thus, one degree of latitude is not exactly one 360th part of a meridian circle. If the earth were a true sphere, arcs in the celestial meridian would correspond with arcs of like number of degrees in the terrestrial meridian; that is, to refer to the above figure, straight lines from the earth's centre, C, to the points *q*, 1, 2, 3, 4, 5, 6, in the heavens would divide the arc P Q on the earth into *six parts exactly equal* to each other; and these points in the heavens would be vertical at the points where these lines would cut the earth's surface.

478. In consequence of the rotatory motion, the parts at a distance from the axis have a considerable centrifugal force, or tendency to fly off in the tangential direction, and they would do so if they were not held together by a firm attractive force; or if the centrifugal force were sufficiently strong. And they have the greater tendency to fly off, the nearer they are to the equator, for the parts at the surface of a rotating body move with different degrees of rapidity, and consequently different degrees of force. The polar points do not move out of their places, but simply turn round during the whole rotation; and each point describes a larger circle of rotation as it is nearer to the equator. Thus, while a person at the equator is carried 24,897 miles by rotation in the 24 hours, one at London moves only 15,500 miles; at the arctic circle, about 10,000 miles in the same time. But, by the planet's attraction, the parts have also a tendency towards the centre, in the direction of the radius; and as the tendency to fly off acts in some degree against the tendency to the centre, it neutralizes a part of that tendency, and thus

diminishes the gravitating force sensibly where the centrifugal force is great; that is, in the equatorial regions.

479. As the centrifugal force of a rotating body thus lessens gravity towards the equatorial regions, the parts there are urged outwards by this centrifugal force, until an equilibrium is induced by the increased quantity of matter between the centre and the equatorial regions.

480. By these forces it is at once evident that in a rotating body the greater centrifugal force in the equatorial regions would cause a bulging out of these regions, if in the fluid state. But even were a planet, such as the earth, with large portions of its surface covered with water, mainly in the solid state and perfectly spherical at first, a rotatory motion would cause a polar compression. For, the parts at the surface *in the liquid form* would be thrown towards the equatorial regions, and heaped up there, while the polar regions would be left dry. Again, as the parts at the surface are elevated by volcanic heat, and thus to a certain extent movable, and the earth is continually worn down by the action of disintegrating agents, diffused through the waters and thus rendered loose and movable, subsiding afterwards and filling up the lower parts of the deep seas,—the excess of land near the poles might be in time removed, spread out over the equatorial regions, and thus an equal distribution of land and sea might take place over the whole.

481. In the case of the earth it is probable, from geological considerations, that the spheroidal form was assumed while it was mainly or entirely in the fluid state; the opinion being held that the earth was at one time wholly, and that it is still partially, in a molten, fluid state.

482. Next, the spheroidal form of the planet also lessens the force of gravity about the equatorial regions; the parts there being further from the centre. Hence, even though the planet did not rotate, if it had the spheroidal form, the force of gravity would be somewhat greater at the flattened than at the projecting parts. Thus, *directly*, by giving the great centrifugal force to

the parts in the equatorial regions; and *indirectly*, in causing the spheroidal form, the rotatory motion is the source of the differences of the force of gravity at different latitudes.

483. Accordingly, it is actually found that a body weighs less, or produces less downward pressure, in proportion as it is nearer to the earth's equator; that its gravity increases as we approach either pole. This difference in the force of gravity at the poles and middle regions cannot be manifested by a common balance, as the weights used would be as much affected as the body to be weighed. But it is at once detected by a spring balance, or by the pendulum. The spring is less stretched by the same body in proportion as the distance from the pole is greater: and the pendulum vibrates slower. Both of these circumstances indicate a diminution in the force of gravity. For particulars, see the description of the earth in Sect. VI.

SECTION V.

General Facts relating to the Solar System.

484. The solar system, as presently known to astronomers, consists of 160 distinct bodies, viz., the **Sun**; 9 large planets revolving around him in nearly circular orbits; 132 asteroids, or small planetary bodies, between the orbits of Mars and Jupiter; 18 moons or satellites, one of which belongs to the earth, and all the others to the four most distant planets; together with a host of comets and countless myriads of meteorites. The large planets, in the order of their distance from the sun, are:—**Vulcan** (whose existence is somewhat doubtful), **Mercury, Venus,** the **Earth, Mars, Jupiter, Saturn, Uranus,** and **Neptune.** The asteroids have all been discovered during the present century, the first of them (Ceres) having been detected on January

1, 1801 (see par. 571). Owing to its proximity to the sun, Vulcan is never seen by the naked eye, and Mercury very seldom, nor can Uranus or Neptune, owing to their vast distance from the sun and earth, while the asteroids are invisible on account of the smallness of their dimensions. Hence, with the exception of Mercury, all these bodies were wholly unknown to the ancients.

485. All the planets move round the sun in the same direction as the earth—*west by south to east;* and their rotations on their axis are in the same direction—*from west to east.*

486. La Place calculated that the probability is as four millions to one that all the motions of the planets, both of rotation and revolution, were imparted at the same time by one original cause, common to them all.

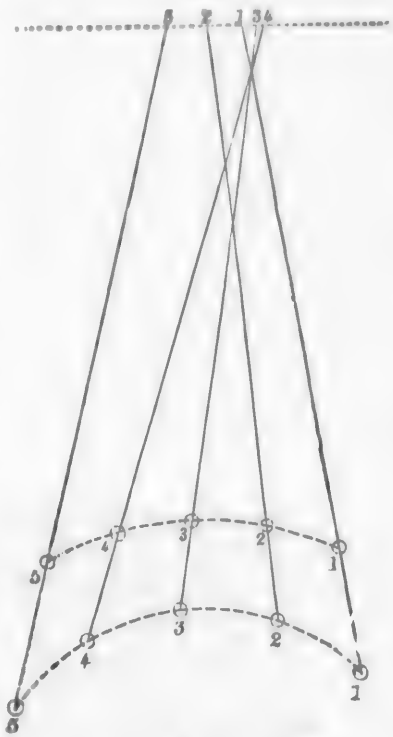
487. The planes of the orbits of the principal planets are not much inclined to that of the earth's orbit; but all are inclined to it a little, so that one half of a planet's course lies north of the plane of the ecliptic—the other half south of it. From the orbits of the leading planets being a little above or below the plane of the ecliptic, they always appear near the ecliptic. Few lie beyond the zodiac.

488. If a spectator were to view the solar system from a point on the *north* side of the planes of their orbits, the planets and satellites would appear to move in a direction opposite to that of the hands of a watch, as in Fig. 47 and Fig. 18; and this is the manner in which the courses of the planets, etc., are usually represented in diagrams.

489. From the earth, as well as each of the planets, being in motion round the sun, the planets appear at times to be actually stationary in the heavens, or even to move back, *i.e.*, in a retrograde direction. But these apparent irregularities can be explained and calculated: the real motion of all is from west to east. The retro-

grade movement of a planet may be understood from the adjoining figure. If a planet, moving in the orbit represented in the lower curve, move through the distances between the successive numbers in the same time as the planet in the upper curve moves between the corresponding numbers, both starting together from the positions numbered 1, then the planet in the upper curve will appear to those who view it from the other planet to move from 1 to 2 in the sky—represented by the dotted line at the top; then from 2 to 3, a *retrograde* movement; then from 3 to 4, also *retrograde;* and then will resume its original direction, and pass from 4 to 5.

Fig. 80.



490. Though the planets appear as mere points to the naked eye, they present discs of considerable breadth when viewed through telescopes even of very moderate magnifying power.

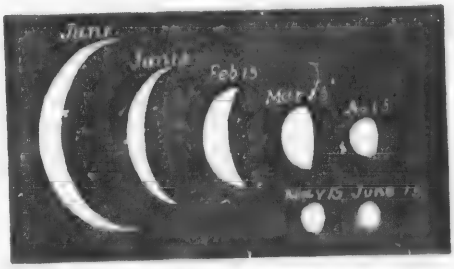
491. This affords a very striking illustration of the remoteness of the fixed stars: an ordinary telescope magnifies a planet

into a perceptible disc, or breadth of surface; but the fixed stars, viewed by the most powerful telescopes, still appear as mere luminous points.

492. The part of any planet which is turned towards the earth will always be *one-half of its spherical surface*, and it will appear as a flat circular surface when the whole of the part next us is visible, just as the sun and full moon appear; while, if less than the whole of the half next us be visible, the planet's disc will be proportionately less, and not of a circular form.

493. The planets and satellites do not shine by their own inherent light, but by reflecting the light which they receive from the sun. This is known by the **phases** which they present, for a planet varies in the magnitude of the illuminated surface which is turned towards us; and it is found that, *of the side which is next us, that part only appears luminous which is at the same time turned towards the sun, so as to receive his light.* The adjoining figure represents the phases of

Fig. 51.



Venus for the year 1851, as they appeared in the telescope.

494. The nine leading planets may be arranged in two characteristic groups—the *interior*, those nearer to the sun than the asteroids; and the *exterior*, those beyond the asteroids. The interior are Vulcan, Mercury, Venus, the Earth, and Mars; the exterior are

Jupiter, Saturn, Uranus, and Neptune. The following differences are found between these two groups:—1. The average equatorial diameter of the exterior planets is about 9¼ times that of the interior planets. 2. The average density of the interior planets (1·03) is nearly six times that of the outer planets (0·172). 3. The average day (time of rotation) of the inner planets (24h. 1m.) is more than double that of the outer planets (9h. 45m.). The exterior planets have each several satellites, and one has a ring, while, excepting the earth, which has one satellite, no such appendages are found attending the interior planets.

SECTION VI.

Of the Sun, Planets, Satellites, and Comets.

The Sun (*Sol*), ☉

495. The sun is the centre of the solar system, and is a globular body of immense magnitude.

496. Its *mean* distance from the earth has within the last ten years been ascertained to be about ninety-two millions of miles (92,093,000); or about 23,315 times the length of the earth's polar radius. But the earth is nearly three millions of miles nearer to the sun in our winter than in our summer.—See Earth.

497. The sun is not perfectly spherical; but, like all the planets, is flattened at the two opposite points, termed poles. Its form is, therefore, a spheroid, like an orange. The sun's polar diameter is about eight hundred and fifty-two thousand miles (852,389):—or 108 times the length of the polar diameter of the earth.

498. The magnitude (or volume) of the sun is to that of our earth as 1,245,130 to 1.* That is, the sun is extended through 1,245,130 times the space occupied by the earth. The gravitating force, or mass, of the sun is to that of the earth as 314,760 to 1; and is more than 745 times that of all the planets taken together. As the sun exceeds the earth so much more in bulk than in weight, the density† of the sun must be less than that of the earth: the sun's density is little more than one-fourth of that of the earth, or as 0·25 to 1.

Hence, owing to the comparatively small gravitating force of the sun's matter, and the distance from the surface to the centre, the force of gravity at the sun's surface is only 27·2 times that at the earth's surface. A body, therefore, which at the earth's surface would compress a spring to an extent indicating a weight of one pound, would, at the surface of the sun, compress that spring as much as 27·2 pounds would at the earth's surface.—The equatorial circumference of the sun is about 2,680,000 miles.

499. The sun rotates upon its axis in a little more than twenty-five days ($25^{d.}\ 7^{h.}\ 48^{m.}$) in a direction from west to east. This is ascertained by observation of the motion of the spots on his surface. These are found to disappear on one side, while others appear on the opposite side, move round in the same direction, and disappear in their turn on the same side as the former. The uniform progressive motion of the spots, and in the same direction, can only be explained by a rotatory motion of the body of the sun in that direction.

500. "It has been found, however, that the spots, caused by their being carried round by the sun in its rotation, have a motion of their own. This *proper motion*, as distinguished from their *apparent* motion, has recently been investigated in the most complete manner by Mr Carrington. What he has discovered shows that there need be no wonder that different observers have varied so greatly in the time they have assigned to the sun's rotation. He shows that all sun-spots have a

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* The magnitudes of spheres are as the cubes of their diameters,—that is, in the present instance,

Magnitude of earth : Magnitude of sun :: 1^3 . 109^3 :: 1 : 1,245,130

† Specific gravity, or comparative quantity of gravitating matter in the same volume.

movement of their own, and that the rapidity of this movement varies regularly with their distance from the solar equator. The spots near the equator travel faster than those away from it, so that if we take an equatorial spot we shall say that the sun rotates in about twenty-five days; but if we take a spot situated half-way between the equator and the poles, in either hemisphere, we shall say that it rotates in about twenty-eight days."—*Lockyer's Elementary Astronomy.*

501. The sun's axis is not perpendicular to the plane of the earth's orbit; it leans 7° 15′ from the perpendicular; forming therefore an angle of 82° 45′ with the plane of the ecliptic.

502. It may now be regarded as certain that the sun is not fixed in one spot, but that it has a *proper motion*, as it is termed, through space, carrying the planets, etc., along with it. See par. 707.

503. The sun has two *apparent motions*, one daily, through the sky, giving rise to the alternations of night and day; another yearly through the constellations of the zodiac, causing its different degrees of elevation above the horizon at different periods of the year. These apparent motions of the sun are caused, the first by the rotation of the earth on its axis, the latter by the earth's annual revolution round the sun.

504. The sun is considered to be opaque in its body, but to be surrounded by a highly luminous atmosphere, from which emanate the rays that cause light and heat when they strike upon bodies.

505. Viewed through a telescope, the sun presents a somewhat mottled appearance, with minute shady spots scattered through the luminous matter. Large dark spots, which are not permanent, and which change both in size and form, are seen upon its surface. These are termed **maculæ**: they consist of a dark or black part in the centre, called *nucleus*, with a surrounding part not so dark, termed *penumbra*. In the vicinity of the spot, brilliant and highly luminous streaks are seen; these are named **faculæ**.

506. The maculæ are found only about the equatorial regions of the sun. Their magnitude is very various—from a few hundreds to upwards of 45,000 miles. A circle of 461 miles in diameter, corresponding to a single second of angular measure on the sun's disc, is the least space which can be distinctly discerned on the sun as a visible area. "Herr Schwabe, of Dessau, has very recently made a most interesting discovery regarding these sun-spots, viz., that *they increase and decrease in frequency periodically.* He has shown that in the course of about ten and a half years they pass through a complete cycle of changes. They become gradually more and more numerous up to a certain maximum, and then as gradually diminish. At length the sun becomes not only clear of spots, but a certain well-marked darkening around the border of his disc disappears altogether for a brief season. At this time the sun presents a perfectly uniform disc. Then gradually the spots return, become more and more numerous, and so the cycle of changes is run through again. There seems every reason for believing that these periodic changes are due to the influence of the planets, especially of Jupiter, upon the solar photosphere; though in what way that influence is exerted is not at present perfectly clear. Some have thought that the mere attraction of the planets tends to produce tides of some sort in the solar envelopes. Another equally interesting discovery is closely allied to that now mentioned. It appears that the periodic changes in the solar spots are associated with the periodic changes in the character of the earth's magnetism. The sun-spots vary in frequency within a period of ten and a half years, and the magnetic diurnal vibrations vary within a period of the same duration. They agree most perfectly, not merely in length, but maximum for maximum and minimum for minimum. When the sun-spots are most numerous, then the daily vibration of the magnet is most extensive,

while, when the sun's disc is clear of spots, the needle vibrates over its smallest diurnal arc. In short, such is the bond of sympathy between the earth and the sun, that no disturbance can affect the solar photosphere without affecting the earth, and doubtless all the other planets, in a greater or less degree."—*Other Worlds than Ours*, p. 26, *et seq.*

507. It is but very recently that astronomers arrived at any definite knowledge of the **physical constitution of the Sun**, and this knowledge has resulted form a skilfully contrived instrument called the *Spectroscope*. Sir Isaac Newton showed that if a pencil of solar light be introduced into a dark room through a small round aperture in the window-shutter, and be then made to pass through a glass prism with its refracting angle downward, an oblong rainbow-coloured picture of the sun, called the *solar spectrum*, will be formed on the opposite wall, or on a white vertical screen placed in a line with the glass prism and the aperture. The prism has analyzed or decomposed the pencil of colourless light, and portrayed its seven constituent colours (violet, indigo, blue, green, yellow, orange, red), according to their various degrees of refrangibility, on the wall or screen. By employing another prism he re-combined these seven coloured rays, and reproduced the clear, transparent, solar ray; but here his beautiful discovery ended. In 1802, Wollaston discovered that there were *dark lines* crossing the spectrum in different places. Subsequently, a celebrated German optician, named Fraunhofer, mapped down the principal of these lines with great exactitude. He also discovered similar lines in the spectra of the stars. Such lines are now known as the *Fraunhofer lines*, and they have led to the most brilliant discoveries of modern times. Kirchhoff, another celebrated German, has greatly distinguished himself by affording a satisfactory explanation of the dark lines; while Stokes, Balfour Stewart, Lockyer,

Frankland, and others, in our own country, have powerfully contributed still further to develop the wonderful science of spectroscopy. "They examined the spectra of the light from incandescent substances (white-hot metals and the like), and found that in these spectra there are no dark lines. They examined the spectra of the light from the stars, and found that these spectra are crossed by dark lines resembling those in the solar spectrum, but *differently arranged.* They next tried the spectra of glowing vapours, and they obtained a perplexing result: instead of a number of dark lines across a rainbow-tinted streak, they found *bright lines* of various colour; some gases gave a few such lines, others many, some only one or two. Then they tried the spectrum of the electric spark, and they found here also a series of bright lines, but not always the same series—the spectrum varied according to the substances between which the spark was taken, and the medium through which it passed. Lastly, they found that the light from an incandescent solid or liquid, when shining through various vapours, no longer gives a spectrum without dark lines, but that the dark lines which then appear vary in position, *according to the nature of the vapour* through which the light has passed. Here were a number of strange facts, seemingly too discordant to admit of being interpreted. One discovery only was wanting to bring them all into unison. In 1859, Kirchhoff, while engaged in observing the solar spectrum, lighted on the discovery that a certain double dark line, which had already been found to correspond exactly in position with the double bright line forming the spectrum of the glowing vapour of sodium, was intensified when the light of the sun was allowed to pass through that vapour. This at once suggested the idea that the presence of this dark line (or rather, pair of lines) in the spectrum of the sun is due to *the existence of the vapour of sodium in the solar atmosphere*,

and that this vapour has the power of absorbing the same order of light-waves as it emits. It would of course follow from this, that the other dark lines in the solar spectrum are due to the presence of other absorbent vapours in its atmosphere."—*Other Worlds than Ours.*

508. It is now found that besides sodium (first discovered), the sun's atmosphere contains the vapours of iron, magnesium, barium, copper, zinc, calcium, chromium, nickel, titanium, and probably gold, together with the non-metallic element *hydrogen*, which is largely present. As yet it has not been proved that gold, silver, mercury, tin, lead, arsenic, antimony, or aluminium exist in the sun, though it by no means follows that these, and indeed all the sixty-five elements which are known to exist in our planet, are really absent.

509. Now, if the *vapours* of these metallic bodies exist in such marked quantity in the solar atmosphere, such vapours must arise from molten oceans of these substances covering the sun's surface. This will enable us to form some idea, however inadequate, of the intense heat characterizing the great central luminary. Indeed, it has been calculated that the **heat** thrown out by every square yard of the sun's surface is as great as that which would be produced by burning six tons of coals on it each hour. Now, the surface of the sun amounts to about 2 4,000,000,000 square miles, and there are 3,097,600 square yards in each square mile. Then, with regard to its **brightness**, Sir John Herschel has found that the sun's light exceeds in brilliancy the brightest light we can form, viz., the lime-light (produced by a flame of oxygen and hydrogen playing on a ball of lime made intensely hot), at least 146 times. Now, as the earth is so far away from the sun, and is, moreover, so very small as compared with the sun's volume, it is clear that we receive but a very small portion of the total amount of light and heat which he

is constantly radiating. If we suppose all the light and heat which the sun discharges to be divided into 227 million parts, our earth only receives one of them.

510. As to the transmission of light and heat from the sun to the earth and the other planetary worlds, two leading theories have prevailed. Sir Isaac Newton held that the sun is constantly discharging from his surface inconceivable multitudes of extremely minute luminiferous particles of matter capable of producing, when they strike against bodies, the well-known phenomena of light and heat; but this theory, besides the improbability of a continual loss of substance without any diminution of brilliancy, is not considered to explain satisfactorily the phenomena of light and heat. The opinion now most generally entertained is, that light and heat are to be attributed to *vibrations* or *undulations* in a thin fluid called **ether** diffused throughout space, a fluid supposed to be excited by the presence of luminous and hot bodies into undulations, capable of causing impressions of light and heat on bodies which they meet; that the sun causes these undulations in this ethereal fluid, which being propagated through space in waves, cause heat and light on the surface of the planets.

The Planet Vulcan.

511. The existence of this planet is somewhat doubtful, mainly owing to conflicting evidence. Its supposed discovery was made on 26th March 1859, by M. Lescarbault, a French physician, who observed a round dark object, like a planet, crossing the sun's disc. Having given publicity to his discovery, Leverrier, the eminent astronomer, hastened to the residence of M. Lescarbault, whom he very closely interrogated regarding all the alleged facts. The result was that Leverrier became perfectly satisfied that an intra-Mercurial planet had been really observed. On the other hand, M. Liais

asserts that he was watching the sun in Brazil at the very time when Lescarbault professes to have seen the dark object crossing the sun's disc, and that he is perfectly certain nothing of the kind was visible. Still, this is merely negative evidence, and it does not demonstrate the non-existence of the planet. On 20th March 1862, Mr Lummis, of Manchester, while examining the sun's disc, between the hours of eight and nine A.M., was struck by the appearance of a spot possessed of a rapid proper motion, and of circular form. After following it for about twenty minutes, he was unfortunately called away to other duties; but he has no doubt upon the subject. As the results of Mr Lummis's observations, it is calculated that Vulcan is 13,082,000 miles distant from the sun; that his periodic time of revolution is 19·70 days; his velocity in orbit per hour, 174,000 miles; and his polar diameter 785 miles.

The Planet Mercury, ☿

512. With the exception of Vulcan, this is the nearest of all the planets to the sun, so far as is yet known. His mean distance from the sun is about thirty-six millions of miles (35,649,000). His orbit is rather more elongated than is usual among the planets, his eccentricity (par. 393) being more than a fifth of his mean distance from the sun. He will thus be at one time 2-5ths of his mean solar distance nearer to the sun than at another.

513. Mercury is the smallest of the planets, excepting Vulcan and the asteroids. His diameter is a little less than 3000 miles — correctly, 2962 miles. Mercury rotates upon his axis in 24 hours, 5 minutes, and a few seconds. He completes his course round the sun in nearly 88 days — correctly, 87 days, 23 hours, 15 minutes; moving in his orbit at the amazing rate of 105,330 miles in an hour, or 29¼ miles per second.

514. The orbit of Mercury is inclined about seven degrees to that of the earth: that is, there is an angle of 7° at the intersection of the planes of their orbits (62).

515. This planet can be seen by the naked eye but very seldom, and only for a short time. Being so near to the sun, he is always in that part of the sky close around the sun, and his inferior light is lost amid the sun's rays. He never departs above 29° from the sun, and when he is visible, can only be seen for a little before sunrise and a little after sunset.

516. Mercury occasionally passes directly between the earth and sun; appearing then as a black spot traversing the sun's surface. This is termed a *transit of Mercury over the sun's disc.*

517. Mercury, as seen through a telescope, does not always appear of the same size and form. He has *phases*, like the moon, being sometimes horned like the new moon, sometimes full like the full moon. The cause of these changes is this:—We can see only that part which is illuminated by the sun; and as different quantities of that part are turned towards us successively, we see different amounts of the illuminated half at different times.

518. At Mercury, the sun will present a diameter about two and a half times greater than at the earth. And he will receive nearly seven times as much of the influence which, emanating from the sun, gives rise to the phenomena of heat and light.

The Planet Venus, ♀

519. This planet is the third in order from the sun—her orbit lying between those of Mercury and the earth. Her mean distance from the sun is a little less than sixty-seven millions of miles (66,614,000), Her distance from the sun does not vary much, her eccentricity being only 1-147th of her mean distance from the sun.

520. The polar diameter of Venus is about 7510 miles. She is very little less than the earth, the polar diameter of the latter being only 389 miles more. Venus rotates upon her axis in 23 hours, 21 minutes; and completes her course round the sun in 224 days, 16 hours, and 49 minutes:—moving at the rate of 77,050 miles per hour.

521. The orbit of Venus is inclined about three degrees, twenty-three minutes to the ecliptic (3° 23′): so that the plane of the earth's orbit and that of this planet are nearly coincident.

522. Venus is visible frequently. She is the most beautiful of the planets (whence her name), and, being near to us, she appears as bright and large as Jupiter, although that planet exceeds her very much in magnitude. Venus is seen only about the times of sunrise and sunset; but is visible for a much longer time before sunrise and after sunset than Mercury, departing much further from the sun than that planet can do,—namely, to a distance of forty-seven degrees (47°) from that luminary. When seen before sunrise, Venus is well known as *Phosphorus*, *Lucifer*, or *the morning star;* when she appears after sunset, she is termed *Hesperus*, *Vesper*, or *the evening star.*

523. The *transit of Venus over the sun's disc* is a rare occurrence, for the same reasons assigned above for the rare occurrence of the transit of Mercury. The transit of Venus takes place alternately at intervals of 8, 122, 8, 105, 8, 122, etc. years. The last was in 1769, the next will be in 1874, and there will be another in 1882.—This phenomenon is of great use in practical astronomy:—it has been taken advantage of to aid us in determining exactly the sun's distance.

524. Venus exhibits phases, as Mercury and the moon do, and for similar reasons. She appears to us of very different degrees of magnitude and brilliancy; being only 25,479,000 miles distant when nearest to us, and then receding till she is about six times that distance from the earth (see Fig. 51).

525. At Venus, the diameter of the sun appears about one-third greater than at the earth; and his apparent surface dimensions, on which, of course, his heating and illuminating powers depend, are greater in the proportion of sixteen to nine.

526. The axis of this planet leans very much towards the plane of her orbit, forming with it an angle of only 15 degrees; that is, inclining 75 degrees from the perpendicular. Her tropics are therefore only 15 degrees from her poles, and her polar circles only 15 degrees from her equator. This gives rise to some striking peculiarities in the constitution of Venus; namely, that there is much greater diversity of seasons than prevails on the earth,—that the days are much longer where it is summer, and much shorter where it is winter,—that a larger proportion of the regions about the poles have day or night for several rotations,—and that the middle or equatorial regions have two summers and two winters in each of her years.

527. This planet is believed to be surrounded by an atmosphere: and it has been conjectured that she may have a satellite, though that idea is now discredited.

The Planet Earth (*Tellus*), ⊕

528. The next planet after Venus, in order from the sun, is that which we inhabit; having its orbit situated between those of Venus and Mars.

529. The mean distance of the earth from the sun is about ninety-two millions of miles (92,093,000). Her eccentricity is about $\frac{1}{60}$, or 0·0167918. The least distance of the earth from the sun is about ninety and a half millions (90,562,000) miles; the greatest distance about ninety-three and a half millions (93,624,000) miles. The earth is in its *aphelion* on the 1st of July; in its *perihelion* on the 31st of December. The sun, therefore, appears larger on December 31 than on July 1, in the proportion of $32\frac{1}{2}$ to $31\frac{1}{2}$.

530. If the mean distance of the earth from the sun be 1·00000, its distance on July 1 is 1·01679; on December 31, 0·98321.

531. The mean diameter of the earth is 7912 miles; the shorter or *polar* diameter is 7899 miles; the longer or *equatorial* diameter, 7925 miles. The difference between the polar and equatorial diameters is therefore 26 miles. The equator, or circumference of the earth at the widest part, is 24,907 miles in length,*—about 25,000 miles. A degree of longitude at the equator is 365,144 feet, or 69 British miles and 824 feet.

532. The earth's surface is marked by lines in the same manner as the sphere of the heavens.—See **Parallels, Meridians, Latitude, Longitude,** in the first section of Part III.

533. From the spheroidal form of the earth, the degrees of latitude are not all of the same magnitude, but increase from the equator towards either pole. The following table shows the length at every 30° of latitude:—

Latitude.	Length of degree in English feet.
0° (Equator)	362,734
30°	363,641
60°	365,454
90° (Poles)	366,361

Degrees of longitude, of course, gradually diminish from their greatest, at the equator, to nothing at the poles. The following tables represent the length of a degree of longitude at every 5° latitude, and at four leading latitudes:—

Latitude.	English miles.	Latitude.	English miles.
0°	69·07	50°	44·35
5°	68·81	55°	39·58
10°	67·95	60°	34·53
15°	66·65	65°	29·15
20°	64·84	70°	23·60
25°	62·53	75°	17·86
30°	59·75	80°	11·98
35°	56·51	85°	6·00
40°	52·81	90°	0
45°	48·78		

* The circumference of a circle is obtained by multiplying its diameter by 3·14159.

23° 28′ (Cancer)	. . . . .	nearly 63 miles.
51° 32′ (London)	. . . . .	— 48 —
55° 57′ (Edinburgh)	. . . . .	— 38½ —
66° 32′ (Arctic Circle)	. . . . .	— 28 —

534. The earth turns upon its axis in 23 hours, 56 minutes, 4·09 seconds. This is a true or **sidereal day** (300).

535. The equatorial parts of the earth's circumference revolve at the rate of 17·3 miles per minute, or 1038 miles an hour.

536. The interval between two successive appulses of the *sun* to the meridian of a place is termed a **solar day**; that is, the time from the sun being on the meridian of a place till the earth's rotation brings it round again to the sun.

537. The earth completes her revolution round the sun in 365 days, 5 hours, 48 minutes, 49·7 seconds; which period is termed a *tropical year*. The earth's orbit is 578,000,000 miles in length; and her daily motion in her orbit 1,572,892 miles, or 65,533 miles an hour; that is, at the mean rate of 18¼ miles in a second, or 1092 miles every minute.

538. The *sidereal year* (see Precession of the Equinoxes) is longer than the tropical year by 20 minutes, 19·9 seconds; being 365 days, 6 hours, 9 minutes, 9·6 seconds.

539. The mean diameter of the sun, as seen from the earth, is about half a degree, or thirty-two minutes (32′). Its apparent diameter on the 1st of July, when furthest from us, is 31′ 32″—on the 31st December, when nearest to us, 32′ 36″.

540. That is, supposing a great circle of the heavens to be divided into 360 equal parts, the sun's diameter would be equal in length to one-half of one of these parts or degrees.

541. The mean daily motion of the earth is 59′ 8·33″; motion on 31st December, 1° 1′ 9·9″; on 1st July, 57′ 11·5″. The mean velocity being 1·00000, the velocity on 31st December is 1·03386; on 1st July, 0·96671.

542. The axis of the earth is considerably inclined to the plane of its orbit. It makes an angle of 66° 32′ 36″ with the ecliptic, thus leaning 23° 27′ 24″ from the perpendicular to the orbit. Hence arise the changes

in the seasons and in the length of the day.—See Seasons.

543. Hence, the *tropics*, representing the furthest north and south parallels at which the sun is vertical, are 23° 27′ 24″ from her equator; and her *arctic circles*, the parallels within which the sun does not set or rise for several rotations, are 23° 27′ 24″ from her poles. The extent of the inclination may be seen in Fig. 10, page 26. Let the line *a o* represent the ecliptic; then N S will show the direction of the axis, forming an angle of 23° 27′ 24″ with Z *n*, the perpendicular—or, an angle of 66° 32′ 36″ with *a o*.

544. As the direction of the earth's axis, at any time, is always parallel to its direction at any other time, and the greatest distance of any two positions of the earth (from its aphelion to its perihelion) shrinks to a point in comparison with the distance to the fixed stars, the earth's axis during the year always points to the same place in the starry heavens, close to the north pole-star (56): though its direction does change in a very long series of years;—see "Precession."

545. The mean density of the earth has not yet been absolutely ascertained, though, as the result of numerous elaborate experiments conducted by eminent astronomers, during the last hundred years, there can be no doubt that the mean specific gravity of our planet is at least five and a half times that of distilled water at the temperature of 68° Fahr. The famous Schehallien experiment, conducted by Maskelyne in 1774, indicated a density of only 4·713. By certain pendulum experiments, conducted on Mont Cenis by Carlini, at a much later date, the mean density is 4·950. In 1798, the celebrated Mr Henry Cavendish, by an ingeniously executed experiment, arrived at a result of 5·480. More recently, the late F. Baily carefully repeated the Cavendish experiment with consummate skill and patience, and obtained as his result 5·660. The present Astronomer-Royal (Mr Airy) has also conducted an elaborate pendulum experiment, in the

Harton coal-pit, near South Shields, by which he estimates the density of the earth as 6·565, a result which we have no doubt the progress of science will show to be greatly too large. The accomplished author of "Life and Work at the Great Pyramid in 1865," conclusively shows that the architect of that stupendous structure knew the specific gravity of our planet upwards of 4000 years ago, and gave it as 5·7 times that of pure water at 68° Fahr.* Seeing that all the other physical revelations treasured up in that profoundly mysterious pile have been found to be in exact harmony with the latest results of modern science, we entertain very little doubt that the specific gravity which it assigns to the earth will be found altogether reliable. The immortal Newton predicted, some two hundred years ago, that the density of the earth would be found to lie between five and six times that of water.

546. Experiment shows that the force of gravity at the earth's surface causes a body to fall $16\frac{1}{12}$ feet in the first second, *three times* that amount in the next second, *five times* $16\frac{1}{12}$ in the third second, etc. The force of gravity at the earth's equator is diminished about 1-289th by centrifugal force: from this cause alone, therefore, a body will weigh 1-289th less than at the poles. From the spheroidal form of the earth, the force of gravity is 1-590th less at the equator than at the poles. The total difference in the force of gravity at the poles and equator is equal to the sum of these quantities, or 1-194th, for $\frac{1}{289}$ and $\frac{1}{590}$ make $\frac{1}{194}$. Accordingly, a body which weighs any given quantity at the poles, as indicated by a spring balance, must be increased in weight by 1-194th part, to produce the same effect on the spring at the equator.†

* See Life and Work at the Great Pyramid in 1865, by C. Piazzi Smyth, Astronomer-Royal for Scotland (Edinburgh, Edmonston and Douglas).

† The increase of the force of gravity from the equator towards either pole is in the proportion of the *square of the sine of the latitude*.

547. The earth is found, in every part where it has yet been tried, to become sensibly and regularly warmer in proportion as the distance below the surface is greater — the temperature increasing about one degree Fahrenheit for every descent of 55 feet. Calculating at this rate of increase, a temperature of 2400° Fahr. would be reached at a depth of twenty-five miles, sufficient to keep in fusion such rocks as basalt, greenstone, and porphyry; at a depth of thirty-six miles, the temperature would be 3272°, sufficient to melt iron; and at a depth of fifty-four miles, a heat of 4892° would prevail—a temperature at which all known substances would pass into the liquid or molten form. The phenomena of hot springs, volcanoes, and earthquakes, afford other and independent evidence of the intense heat prevailing in the interior of our planet. From an apparent coincidence between the positions of the moon in relation to the earth, and the periods at which many earthquakes have occurred, it has been conjectured by M. Perrey of Dijon, that earthquakes may be caused by the attraction exercised by the moon on the fluid mass in the interior of the earth.

The Moon (*Luna*), ☽

548. The moon is a satellite or secondary planet to the earth, round which it revolves, and with which it is carried annually round the sun.

549. The mean distance of the moon from the earth is about two hundred and forty thousand miles (238,793), or 60·2734 times the equatorial radius of the earth. Her distance from the earth does not vary much. Her eccentricity is about 1-20th of her mean distance from the earth, or about 13,000 miles.

550. The earth will appear at the moon about 13 times larger than the moon does to the earth, and supply that satellite with a proportionately more brilliant light than she affords to us.

551. The diameter of the moon is 2158 miles, a little more than 1-4th of that of the earth. The bulk of the moon is about $\frac{1}{49}$th of that of our earth, or as ·02012 to 1: her mass is about $\frac{1}{80}$ (·0125) of that of the earth; her density 0·62, that of the earth being 1.

552. The moon performs her revolution round the earth in 29 days, 12 hours, 44 minutes. This is the

period from one new moon to the next,—from the time of the moon being in conjunction with the sun till she comes to the the same position again,—and it is termed a *lunar* month, a *synodical* month, or her *synodical* revolution. She moves in her orbit at the rate of 2-3ds of a mile each second, 37·9 miles in a minute, or 2277 miles per hour.

553. The period of the moon's rotation on her axis is the same as that of her revolution round the earth (see 554); and this is the reason why *she always presents the same side to the earth.* And that side is never totally dark, having one fortnight of sunlight, and being illuminated by the earth the other fortnight. The other side has alternately a fortnight of sunlight and a fortnight of darkness. So far as yet ascertained, all the other satellites belonging to our system follow the same law—that is, they rotate on their axes in the same time as they revolve around their primaries.

554. Viewed, not with respect to the sun, but to the stars, the moon is found to return to the same star in 27 days, 7 hours, 43 minutes. This is termed a *sidereal* or *periodical month;* and is the true period of the moon's revolution round the earth and on her axis.

555. The plane of the moon's orbit forms an angle of 5° 8′ 40″ with the plane of the earth's orbit; so that the two orbits are not very far from being in the same plane. The moon's axis scarcely leans towards the earth's orbit, forming an angle of 88° 30′ with the plane of the ecliptic,—or leaning only 1° 30′ to the ecliptic. Being so nearly perpendicular to the plane of the ecliptic—the path in which the moon moves round the sun—the moon can have little or no change in her seasons, or in the length of her day.

556. When the moon is viewed by a telescope, its surface appears irregularly illuminated, with dark and bright parts, now considered to be mountains and valleys; the former very high in proportion to the

magnitude of the moon, some being about five miles in height above the general level of the moon's surface. These mountains have much of a volcanic aspect, with craters of great breadth—some upwards of 100 miles. It was at one time supposed that the darker spots were seas or lakes; but it is now believed that there is no water on the surface of the moon. These mountains have been measured, as to altitude, and names have been assigned to them, taken from the names of celebrated astronomers and other philosophers: as Plato, Tycho, Newton, Flamsteed, Herschel, Huyghens. There is no appearance of clouds, or any indications of an atmosphere on the moon. When the moon presents less than her full enlightened surface to us, the edge next the sun, which is fully illuminated, appears smooth and rounded, while the other appears rough and broken —probably from the hills being enlightened by the sun's rays, while the low grounds are dark. The same side is always turned towards us; but from her motion in her orbit not being uniform, we sometimes see a little of her surface beyond that half on each side; and, from her axis being inclined to the plane of her orbit, we see at times a little beyond her poles. These shiftings of the face next us are termed **librations.**

The Planet Mars, ♂

557. Mars is the next planet beyond the earth, the orbit of this planet lying between those of the earth and Flora, or that Minor Planet which is nearest the sun. It is the first of the superior planets.

558. The mean distance of Mars from the sun is one hundred and forty millions three hundred thousand miles (140,322,000). His distance from the sun varies considerably; his eccentricity is a little less than 1-10th of his mean distance from that luminary.

559. The diameter of the sun, seen from Mars, is to

his apparent diameter at the earth as 21 to 32, nearly as 2 to 3. The sun's influence at Mars is less than one-half of what it is at the earth—correctly, as $92^2 : 140^2$, or nearly as 84 : 196.

560. The polar diameter of Mars is about 4036 miles—a little more than one-half of the earth's diameter. He is sensibly flattened at the poles, his equatorial diameter being 4920.

561. Mars rotates on his axis in 24 hours 37 minutes, and performs his revolution round the sun in in 686 days 23 hours, moving in his orbit at the rate of $14\frac{3}{4}$ miles in a second, or 53,090 miles per hour.

562. The planes of the orbits of Mars and the earth are nearly coincident, the angle between them being one of only 1° 51′ 6″. —See Fig. 52.

563. The axis of Mars is considerably inclined to the plane of his orbit, forming with it an angle of 61° 9′, about two-thirds of a right angle, leaning from the perpendicular about 28° 51′. Therefore there must be a considerable variety in the seasons at Mars—more, proportionally, than at the earth, though less than at Venus.

564. This planet is frequently pretty near the earth, and therefore, though small, appears tolerably large, but much less than Venus or Jupiter.

565. Owing to the great length of the diameter of Mars's orbit, there is a very great difference between his distance from us in opposition and in conjunction; so much so that, while his diameter appears equal to 18″ in opposition, it is only 4″ in conjunction.

565. When viewed through a telescope, Mars is found to exhibit **phases**; his apparent magnitude varying according to the amount of the illuminated part which is turned towards us. This shows that Mars is not self-luminous, but shines by reflecting the sun's light. But he never appears horned, like the new moon, nor even like the half moon. The enlightened portion of his disc is never less than seven-eighths of the whole, being then *gibbous*, or like the moon three or four days before full moon. This shows that Mars's orbit is *exterior* to ours; the *horned* phase can only be presented by a body between us and

the sun. Jupiter, Saturn, and Uranus do ot exhibit any phases at all, a proof at once that their orbits are exterior to ours, and that their distances from the sun are so great compared with ours that we are never very far from the centre of their orbits.

567. The regions about the poles of Mars are observed to be more bright than the other parts. This is doubtless caused by an accumulation of snow and ice around his poles, similar to what prevails in the polar regions of the earth. Snow and ice reflect light brilliantly; and if his poles are covered by these, as ours are, this certainly would give rise to a brilliancy in the appearance of these regions. The conjecture that this whiteness is caused by snow or ice is confirmed by the circumstance that it disappears after long exposure to the sun, and is largest and brightest after the winter of the planet.

568. Mars is believed to possess a considerable atmosphere (to the density of which his ruddy colour has been ascribed), and his surface is variegated in a manner which has been attributed to parts of it being covered with water. "At a meeting of the Astronomical Society two or three years ago, a globe was exhibited by Mr Browning, on which lands and seas were pictured as upon an ordinary terrestrial globe. By far the larger part of these lands and seas were laid down as well-known entities, respecting which no more doubt is felt among astronomers than is felt by geographers respecting the oceans and continents of our own earth. Yet the world which is represented by this globe is one which is never less than 120 times farther from us than our own moon. It is rather singular that the planet Mars—the orb represented by Mr Browning's globe—is the only object in the heavens which is known to exhibit features resembling those of our earth. Astronomers have examined the moon in vain for such features: she presents an arid waste of extinct volcanoes, dreary mountain-scenery surrounding lifeless plains (the *seas* of the old astronomers); an airless hemisphere of desolation which has no counterpart on the terrestrial globe. The planets Jupiter and Saturn, orbs which far transcend our earth in mass

and volume, which are adorned with magnificent systems of subsidiary bodies, and which seem in every respect worthy to be the abodes of nobler races than those which subsist upon our earth, afford no indications which justify us in asserting that they resemble the earth in any of those points which we are accustomed to regard as essential to the wants of living creatures. Nearly the whole of the light which we receive from these splendid orbs is reflected, not from their real surface, but from vaporous masses suspended in their atmospheres. It is, indeed, doubtful whether anything has ever been seen of the real surface of either planet, save, perhaps, that a small spot has here and there been faintly visible through the dense overhanging mantle of vapour. And, strangely enough, the two small planets, Venus and Mercury, which present in other respects the most marked contrast to the giant members of our system, resemble them in this point. Both Venus and Mercury seem to be protected from the intense heat to which they would otherwise be exposed by densely vaporous envelopes, which only permit the true surface of the planets to be faintly seen, even under the most favourable circumstances. The planet Mars, however, discloses to us his real surface, and this surface presents indications which cannot reasonably be doubted to result from the existence of continents and oceans, resembling those of our own earth in all essential features. Moreover, that wonderfully delicate instrument of research, the spectroscope, has confirmed these indications in a manner which hardly suffers any further dubiety to rest upon their meaning." *

569. The presence of an atmosphere around Mars is inferred from the appearance presented when he approaches any star. The star is dimmed, changed in

* See the admirable work, entitled "The Orbs Around Us," by R. A. Proctor, B.A., p. 105. London: Longmans, Green, & Co., 1872. In this work, as well as in the companion volume, "Other Worlds than Ours," the student will find beautifully executed charts of Mars, from drawings by Dawes.

colour, and disappears before it reaches the body of the planet.

The Asteroids.

570. The asteroids, as presently known, consist of 132 small bodies, careering round the sun between the orbits of Mars and Jupiter. They are sometimes denominated *planetoids*, as they resemble planets in everything save size; sometimes *telescopic planets*, as they are not visible to the naked eye, but can only be seen by the aid of the telescope. Ceres, the first of them, was discovered by the astronomer Piazzi on the first day of the present century; the three following—Pallas, Juno, and Vesta—were observed by Olbers and Harding during the following six years; after which no more were detected until 1845, when Hencke discovered Astrea. Since then, scarcely a year has passed without adding one or more to the catalogue of these bodies, which, in the autumn of 1873, numbered no fewer than 132.

571. It would be out of place here to give all the details ascertained regarding these members of the solar system. The following will be found to comprise the principal facts. Their distances from the sun vary from 201 millions of miles, the distance of Flora, to 313 millions of miles, the distance of Maximiliana; and their periods are from $3\frac{1}{2}$ years, the period of Flora, to $6\frac{1}{2}$ years, that of Maximiliana.

572. These planets are very small; none of them can be seen by the naked eye, except occasionally Ceres and Vesta. Pallas, the largest of them, has a diameter of only 670 miles, while many of the smaller ones are less than 50 miles in diameter. "Those last discovered shine as stars of the tenth or eleventh magnitude, and the only way in which they can be detected is to compare the star-charts of different parts of the heavens with the heavens themselves, night after night." *

* Lockyer's "Elementary Lessons in Astronomy," p. 121. London: Macmillan & Co. 1871.

573. Their eccentricities are considerable, and they are remarkable for the great angle which the planes of their orbits form with the ecliptic, the inclinations being as follows:—Vesta, 7° 7′ 56″; Juno, 13° 1′ 9″; Ceres, 10° 36′; Hebe, 14° 47′; Pallas, 34° 43′. See Fig. 52, in which their great departure from the plane of the ecliptic is shown. From their orbits being so much out of the plane of the ecliptic they are seldom seen in the zodiac, being generally above or below it, while all the other planets constantly appear in that zone of the heavens. Hence, these planets are sometimes termed *ultra-zodiacal*, *i.e.*, out of or beyond the zodiac.

574. The asteroids present several peculiarities, in which they differ considerably from the other planets. They are extremely small, while, generally speaking, the planets rather increase in size as they are more distant from the sun. They are comparatively near to each other, whereas a very different law prevails with respect to the other planets. The distance between two planets increases in a very high proportion as they are further from the sun, as follows:—Mercury, 36; Venus, 67; Earth, 92; Mars, 140; Asteroids, 259; Jupiter, 479; Saturn, 878; Uranus, 1766; Neptune, 2766. Also, their orbits are very far out of the plane of the ecliptic, whereas the orbits of the other planets are nearly coincident with that plane. The orbits of Venus, Mars, Jupiter, Saturn, Uranus, form angles with the plane of the ecliptic of from 3° 23′ to 0° 46′, and Mercury of 7°; but the angles which several of the asteroids form with that plane are 5°, 7°, 10°, 13°, 14°, and 34°.—See Fig. 52.

575. The following singular relation has been observed regarding the distances of the planets, and it led to the conjecture of the existence of another planet between Mars and Jupiter, before the discovery of the asteroids.

If the numbers 0, 3, 6, 12, 24, 48, 96, 192, be taken, and the number 4 added to each, the sum will express the proportionate distances of the planets in order from the sun:

0	+	4	=	4,	Distance of	Mercury.
3	+	4	=	7,	...	Venus.
6	+	4	=	10,	...	Earth.
12	+	4	=	16,	...	Mars.
24	+	4	=	28,	...	
48	+	4	=	52,	...	Jupiter.
96	+	4	=	100,	...	Saturn.
				added afterwards,		
192	+	4	=	196,	...	Uranus.

A void being observed between the numbers 16 and 52, Professor Bode conjectured that a planet filling up the vacant number might exist, which was confirmed by the discovery of the asteroids, in the situation in the solar system indicated by the vacant place. This law has failed, however, in the case of Neptune.

576. These peculiarities led to the singular conjecture, that these planets originally formed *one planet;* that that planet has been ruptured by some great convulsion, which has divided the *one* into a number of separate parts, and thrown the fragments out of the former orbit into orbits deviating considerably from the general order. But this is a mere speculation at present, though strengthened by the ascertained intersection of many of their orbits; as, if a planet were so ruptured, the fragments would return periodically to the spot where the explosion had taken place.

The Planet Jupiter, ♃

577. Jupiter is the next planet beyond the asteroids, his orbit lying between them and Saturn. He is the largest of the planets, and, though so remote from the earth, owing to his great magnitude often appears as bright and large as Venus.

578. The mean distance of Jupiter from the sun is about four hundred and seventy-nine millions of miles (479,141,098). His distance from the sun does not vary much, his eccentricity being less than 1-20th of his mean distance.

579. The sun's diameter as seen from Jupiter is only 1-5th of its apparent magnitude at the earth.—correctly, as 6 to 32. The relative proportion of the sun's influence at Jupiter and at the earth is as 1 to 27½ (as

$92^2 : 479^2$). Gravity at his surface is about $2\frac{1}{2}$ times as great as on our earth's; so that such creatures as exist around us would find their weight much more than doubled if they were removed to Jupiter.

580. The diameter of Jupiter is eighty-eight thousand miles (88,400), more than eleven times that of the earth. This is the equatorial diameter. He is about 1387 times larger than the earth. The polar or shorter diameter of Jupiter is about 1-18th, or 5000 miles, less than the equatorial diameter; or, as 83 to 88. The great difference between the polar and equatorial diameters of this planet is attributed to the very great centrifugal force generated by his rapid rotation on his axis. When viewed through a telescope, Jupiter appears of a distinctly oval shape, from the extreme polar flattening.

581. Jupiter turns on his axis in a little less than 10 hours,—correctly, 9 hours, 55 minutes, 28 seconds. His equatorial parts, therefore, revolve at the amazing rate of 7·5 miles in a second, or 453 miles per minute.

582. Jupiter completes his revolution round the sun in $4332\frac{1}{2}$ days, nearly 12 of our years (more correctly, 11 years 314 days):—moving in his orbit at the rate of 8 miles in a second, 480 miles in a minute, or 28,744 miles per hour.

583. The planes of the orbits of Jupiter and the earth are nearly coincident, the angle between them being only $1° 18' 51''$.

584. The axis of Jupiter does not lean more than $3° 4'$ towards the plane of its orbit, being nearly perpendicular to that plane. From this, Jupiter can have little or no variety in his seasons, and little or no change in the length of the day. This planet, therefore, will have a perpetual winter around his poles, and continual summer in his equatorial regions; and the weather comparatively uniform.

585. The density or specific gravity of Jupiter, in common with all the remoter orbs of our system, is

very small as compared with the density of the earth, and of all the planets revolving inside of Jupiter's orbit. Thus, regarding the density of our planet as unity, and that of Mercury, Venus, and Mars as respectively 1·24, ·92, and ·96, we find the density of Jupiter as only ·22, of Saturn ·12, of Uranus ·18, and of Neptune ·17. Be it now remembered that the density of the sun is ·25, or a very little more than the density of Jupiter. We cannot regard this vast difference of density between the superior and inferior members of the solar system as arising from any great difference in the nature of their constituent materials, for the spectroscope has conclusively shown that all the members of the system are in this respect identical with the great central orb. In all probability the cause of the great difference will be found, not in their constituents, but in their condition with respect to their internal heat. Doubtless all the planets had at one time the same temperature as the sun, and were real stars, shining with intrinsic splendour. In the course of ages the smaller planets have gradually cooled down, lost their luminosity, but increased in density. The existence of volcanoes, boiling springs, and increase of temperature as we descend beneath the surface, afford ample evidence that the only member of the solar system which we can fully examine, once possessed a much higher temperature than now; while there appears no reason why the other worlds, which in other respects so closely resemble it, should not resemble it in this also. Jupiter and the other more distant planets have, in like manner, cooled down, but owing to their vastly greater dimensions the progress has been much less rapid, and accordingly their density continues pretty closely to correspond with that of the great central orb. They have not wholly lost their luminosity even, for Jupiter and Saturn exhibit several phenomena which can be accounted for only on the supposition that they are still

faintly glowing.* The larger planets, therefore, of our system cannot, by any possibility, be inhabited by living creatures, though it seems not unlikely that their satellites may.

Satellites of Jupiter.

586. This planet is attended by four satellites or moons, named, respectively, Io, Europa, Ganymede, and Callisto. These cannot be seen by the naked eye, and hence they were not known till after the invention of the telescope. In 1610, within a very short time after the discovery of this powerful instrument of astronomical observation, the satellites of Jupiter were discovered by **Galileo.**

587. The distance from Jupiter of his nearest satellite is 267,000 miles; its diameter is 2252 miles; and it revolves round its primary planet in 1 day, 18 hours, 27 minutes. The distance from the planet of the next satellite is 425,000 miles; its diameter is 2099 miles; and it completes its revolution round Jupiter in 3 days, 13 hours, 14 minutes. Jupiter's third satellite is at a distance of 678,000 miles; its diameter is 3436 miles; and it revolves round Jupiter in 7 days 3 hours, and 43 minutes. The fourth and most remote of Jupiter's satellites is distant from him 1,192,000 miles;—its diameter is 2929 miles;—and it occupies 16 days, 16 hours, 32 minutes in its revolution round Jupiter. The satellites of this planet are rather larger in general than our moon.

588. Jupiter's satellites revolve round him *from west to east*, as the moon does round the earth, and the planets round the sun. The periods of rotation on their axis are the same as their periods of revolution round their primary planet;—obeying, in this respect, the same law as our satellite, the moon.

589. When the body of Jupiter interposes between

* "We are thus led to the conclusion that Jupiter is still a glowing mass, fluid probably throughout, still bubbling and seething with the intensity of the primeval fires, sending up continually enormous masses of cloud to be gathered into bands under the influence of the swift rotation of the giant planet."—*Other Worlds than Ours*, p. 142.

the sun and any of his satellites, that satellite will disappear from our view, *or be eclipsed.*

590. The eclipses of Jupiter's satellites are phenomena of considerable importance in practical astronomy. They afforded the first accurate method of determining the longitude of places on the earth's surface; this mode, however, is now superseded in a great measure by lunar observations.

Velocity of Light.

591. The eclipses of the satellites of Jupiter have been the means of leading to the great discovery that *the passage of light from one point to another is not instantaneous, but requires a certain time;* and they have also enabled the rate of its motion to be calculated. This great discovery was made by **Roemer**, a Danish astronomer, in the year 1675. By observing the eclipse of one of the satellites, he calculated the velocity of light at 192,000 miles per second, inasmuch as it traversed the diameter of the earth's orbit (at that time held to be 190,000,000 of miles) in 16 minutes, 36 seconds. The distance of the earth from the sun, however, can no longer be regarded as 95,000,000 miles, but 92,000,000. This makes the velocity of light, as determined by Roemer, to be 186,000 miles per second. In 1862, **M. Foucault**, a French philosopher, made his celebrated experiments on the velocity of light by means of a rotating mirror, and announced it as 185,170 miles per second, and all astronomers now regard this as the real rate of its velocity.

592. Owing to the great distance of Jupiter from the sun, there must be a considerable difference between his distance from the earth when he is nearest us, or in opposition, and his distance when he is furthest from us, or in conjunction. Now, Roemer found that the eclipses of Jupiter's satellites took place *sooner* than might be expected when he was nearest the earth; and *later* than might be expected when he was most distant from the earth, the total difference amounting to 16

minutes, 36 seconds. This he explained by the supposition that light does not pass instantaneously from one point to another, but requires time for its transmission, and that therefore the rays which intimate to us the eclipse of one of Jupiter's satellites must be longer in coming to us when he is remote than when near, an eclipse in the former case appearing *later* than in the latter. That the variation from the computed time of an eclipse of a satellite of Jupiter is owing to light occupying time in its transmission, was afterwards confirmed by **Bradley**'s great discovery of the Aberration of Light. Thus, we do not see distant phenomena at the actual moment of their occurrence, but some time after, sooner or later according to the distance: a circumstance which the penetration of the illustrious **Bacon** led him to conjecture as being possible, long before there were any means of proving it.

The Planet Saturn, ♄.

593. This is the most remote of the planets known to the ancients and visible to the naked eye. Its orbit lies between those of Jupiter and Uranus. In apparent magnitude Saturn is between Mars and Jupiter, and shines with a rather dull light.

594. The mean distance of Saturn from the sun is eight hundred and seventy-eight millions of miles (878,461,000). His eccentricity is more than 1-18th of his mean distance from the sun. At Saturn, the sun will present a diameter about 1-10th of that seen at the earth. The proportion of the sun's influence which reaches Saturn is about 1-90th of that enjoyed at the earth—as $92^2 : 878^2$.

595. The equatorial diameter of Saturn is about 72,000 miles, and he is about 747 times larger than the earth. The polar diameter of this planet is stated to be 64,714 miles, or 1-9th less than the equatorial. Having a very rapid rotation on its axis, it is to be expected that

Saturn, like Jupiter, will be very much flattened at his poles. He rotates on his axis in 10 hours, 29 minutes. His specific gravity is only ·12, that of our earth being unity, and he is therefore by far the least dense of all the planets.

596. Saturn completes his revolution round the sun in 10,759 days, or about 29½ years;—moving in his orbit at the rate of about 6 miles in a second, or 21,221 miles per hour.

597. The planes of the earth's orbit and of Saturn's are nearly coincident, the angle between them being only 2° 29′ 35″.

598. The axis of Saturn is not at right angles to the plane of his orbit; but makes an angle of about 63° with that plane, leaning 26° 49′ from the perpendicular. There must be therefore considerable variety in the seasons at Saturn. When viewed through a telescope, stripes or belts are observed on Saturn's surface, resembling those seen on Jupiter, but more faint (see 585).

599. The most remarkable features observed about this planet are the enormous **Rings** by which it is surrounded. These very singular appendages (see the representation of Saturn in Fig. 52, page 178) long seemed to be of solid matter; for they throw a shadow on the body of the planet on the side nearest to the sun, while on the other side the body of the planet throws a shadow on the ring; and they are thin, flattish, broad, and generally opaque. They are at a considerable distance from the body of the planet; and consist of **two principal rings**, one within the other, and both in the same plane, which is nearly the same as the plane of the planet's equator. The rings rotate *in their own plane*, in about 10 hours and 32 minutes. Thus, the axis of rotation of the planet and of its ring are nearly the same. A third ring, interior to the others, has been discovered lately. It is dark, and appears in the telescope of a dull purplish hue; while

the luminous rings are bright and whitish yellow, like the body of the planet.

600. The following table exhibits the magnitudes and distances of the exterior luminous rings:—

	Miles.
Exterior diameter of exterior ring,	166,920
Interior ditto,	147,670
Exterior diameter of interior ring,	144,310
Interior ditto,	109,100
Equatorial diameter of the body,	71,904
Interval between the planet and interior ring,	9,700
Interval of the rings,	1,680
Thickness of the rings not exceeding,	100

601. **Galileo**, in 1610-12, observed several remarkable peculiarities in the appearance of Saturn; the exact nature of which he was unable to ascertain. The planet appeared to him to be triple, or to have appendages at the sides like two smaller planets joined to it. In 1655, **Huyghens**, provided with better telescopes, discovered these peculiarities to be caused by a ring surrounding the planet. Towards the close of last century, about 1790, the ring was discovered by Sir William Herschel to be double, consisting of one ring within another, both in the same plane. An inner dark ring has been discovered within these few years by **Galle** of Berlin, **Bond** of Cambridge, U.S., and others; and appearances of lines of division along the various rings have lately led to the supposition that they are composed of innumerable narrow rings.

602. "Of what, then, are these rings composed? There is great reason for believing that they are neither solid nor liquid; and the idea now generally accepted is that they are composed of myriads of satellites or little bodies, moving independently, each in its own orbit, round the planet; giving rise to the appearance of a bright ring when they are closely packed together, and a very dim one when they are most scattered. In this way we may account for the varying brightness of the different parts, and for the haziness on both sides of the ring near the planet, which is supposed to be due to the bodies being drawn out of the ring by the attraction of the planet."*

* Lockyer's Elementary Lessons in Astronomy, p. 117.

Satellites of Saturn.

603. This planet is accompanied by no less than eight satellites. The six which are nearest to the planet have their orbits nearly in the same plane as the ring. The satellites of Saturn are supposed to revolve on their axes in the same periods in which they complete their revolutions round the planet: which has been ascertained of the eighth. They are believed to vary in size from 500 to 3300 miles in diameter. "The eight satellites, taken in their order from the planet, cover spaces on the Saturnian heavens which bear to the space covered by our moon the respective proportions of 2, 1, $1\frac{1}{4}$, $\frac{3}{4}$, $\frac{5}{8}$, $\frac{1}{3}$, $\frac{1}{100}$, $\frac{1}{400}$. In all, then, they cover an area about six times that of our moon. But as, owing to their great distance from the sun, they are illumined by only $\frac{1}{100}$ of the light which illuminates our moon, they can only send back to the planet about $\frac{1}{18}$th part of the light we receive from the full moon, even if it were possible for them to be all full at once." —*Other Worlds than Ours.*

604. The *first* satellite is at a distance of about 120,000 miles from Saturn, and revolves round it in 22 hours, 37 minutes:—the *second* is about 155,000 miles from the planet, and completes its revolution in 1 day, 8 hours, 52 minutes:—the *third* is about 191,000 miles from Saturn, and its period is 1 day, 21 hours, 18 minutes:—the distance of the *fourth* is about 246,000 miles; its period 2 days, 17 hours, 41 minutes:—the *fifth* is about 343,000 miles from Saturn, and revolves round him in 4 days, 12 hours, 25 minutes:—the *sixth* is about 796,000 miles from the planet, and revolves round him in 15 days, 22 hours, 41 minutes:—the distance of the *seventh* is about 1,007,000 miles, and its period 21 days, 7 hours:—the *eighth* is about 2,314,000 miles from Saturn; and its period, 79 days, 7 hours, 55 minutes.

605. The satellites of Saturn were discovered by **Huyghens, Cassini, Herschel, Lassel,** and **Bond**;—one by **Huyghens** in 1655,—four by **Cassini** in 1671 and subsequent years,—two by **Sir W. Herschel** in 1789,—and one (the seventh) in 1848, on the same day, by Lassel in Liverpool, and Bond in Cambridge, United States. The satellites of Saturn have received the names Mimas, Enceladus, Tethys, Dione, Rhea, Titan, Hyperion, Japetus.

The Planet Uranus, ♅

606. Though Uranus is of considerable magnitude, it is rarely and with difficulty seen by the naked eye, owing to its great distance. This planet was discovered by the celebrated astronomer **Sir William Herschel,** on the 13th of March 1781. It was called by him "Georgium Sidus," in honour of George III., and by some astronomers, "Herschel," in honour of the discoverer. The name Uranus, however, from one of the characters in the ancient mythology, is preferred, as being more in harmony with the appellations of the other planets.

607. The mean distance of Uranus from the sun is seventeen hundred and sixty-six millions of miles (1,766,565,000), a little more than 19 times the distance of the earth from the sun. The distance of Uranus from the sun does not vary much, his eccentricity being less than 1-20th of his mean distance.

608. The sun's diameter appears at Uranus of 1-19th his apparent magnitude at the earth, or as $1\frac{2}{3}$ to 32: and the proportion of the sun's influence enjoyed by this planet is only 1-368th of that experienced at the earth: as 92^2 to 1766^2.

609. The polar diameter of this planet is 29,722 miles; his equatorial diameter, 33,024 miles; his volume, 72 times that of the earth; but his density is so small (·18) that his weight or mass is only 12·64 times that of our planet, and the force of gravity at his surface only $\frac{1}{20}$th greater than at the earth's.

610. Uranus completes his revolution round the sun in 30,686 days, about 84 years;—moving in his orbit at the rate of 4 miles in a second, or 14,963 miles per hour.

611. The plane of the orbit of Uranus is more nearly coincident with that of the ecliptic than in the case of any other planet, the angle between them being only 0° 46′ 28·4″. The inclination of the planet's equator to the plane of his orbit is

believed to be about 76°. From this, it follows that the Uranian sun, which has an apparent magnitude of only $\frac{1}{368}$th part his size as seen from the earth, has a range of about 76° on either side of the celestial equator, and that he will continue 23½ of our years above the horizon, while in winter he will continue for the same period of time under the horizon. These facts have a most important bearing on the question of the habitability of the planet. It seems certain that none of the animals or plants with which we are acquainted could possibly live either on Uranus or Neptune. Indeed, it is far more probable that, like Jupiter and Saturn, these planets perform the part of suns to the systems of satellites which respectively revolve around them, affording to the latter a large amount of heat, together with, possibly, an appreciable amount of light also (585).

Satellites of Uranus.

612. This planet is known to be attended by at least four satellites, known as Ariel, Umbriel, Titania, and Oberon. The latter two were discovered by Sir W. Herschel in 1787. Umbriel was discovered by Otto Struve in 1847, and Ariel in the same year by Lassel of Liverpool. Ariel, the nearest to the planet, is 123,000 miles distant; Umbriel, 171,000; Titania, 281,000; and Oberon, 376,000 miles. The first revolves round his primary in 2 days 12 hours, and the last in 13 days 11 hours. Hitherto their magnitudes have not been determined.

613. These satellites present some remarkable peculiarities and departures from the usual order in the solar system. The planes of their orbits are nearly perpendicular to the plane of Uranus's orbit, forming an angle of 78° 58′ with the plane of the ecliptic (which is nearly the plane of Uranus's orbit); and they do not move in the same direction which prevails everywhere else in the solar system, viz., from *west* to *east;* but in a retrograde direction, *i.e.*, from *east* to *west.*

The Planet Neptune,

614. This recently-discovered planet is the most distant member of the planetary system, so far as we know at present. Neptune is a planet of considerable magnitude, being 36,620 miles in diameter; and he revolves round the sun in about 164·6 years (60126·7

days), at a mean distance of 2766 millions of miles. The inclination of his orbit to the ecliptic is 1° 47′; and one satellite has been observed near him, which revolves round him in $5^{d.}$ $21^{m.}$, at a distance of about 220,000 miles. It is probable, however, from the analogy of Jupiter, Saturn, and Uranus, that he has a greater number of moons attendant upon him.

615. Neptune was discovered in an interesting and very remarkable manner. In the year 1846, his existence and position were predicted simultaneously by two astronomers, **M. Leverrier** of Paris, and **Mr Adams** of Cambridge. On the 23d of September in that year, "a day," says Sir John Herschel, "for ever memorable in the annals of Astronomy," **Dr Galle**, of the Royal Observatory at Berlin, received a letter from **M. Leverrier**, requesting him to look for the predicted planet about the place in which he had calculated it should be found. **Dr Galle** did so on that very night, and found the new planet within one degree of the place assigned to it by **M. Leverrier.** Next night it was found to have moved from its place, and repeated subsequent observations have fully confirmed the existence of this new planet, and enabled its orbit, period, and distance to be laid down correctly.

616. As already mentioned, the mutual actions of the planets on each other cause *disturbances* in their movements; that is, deviations from the course which each would pursue if influenced only by the sun's attractive force and its own projectile energy. As might be expected, these disturbing forces produce considerable effects among the more remote planets where the sun's influence is comparatively weak. Soon after the discovery of Uranus in 1781, it was found, on searching the astronomical records, that he had been seen often by previous astronomers, once so far back as 1690, though not even conjectured to be a planet. But it was observed, on calculating what his position should have been at former times, to judge from the ascertained elements of his orbit, that, making every allowance for disturbances by known planets, the recorded positions were far from coinciding with those assigned by computation. Moreover, his actual course after discovery did not coincide with the theory

deduced from the elements of his orbit as found by the first observations. Up to 1830-1, his real position was continually in advance of his computed position; about that time they corresponded, subsequently he fell behind his calculated positions. The true cause, the disturbing influence of a more remote planet, had been conjectured by several astronomers. Simultaneously, **Leverrier** and **Adams**, from the observed deviations, deduced the mass of the previously unknown disturbing body; and assigned its *position* within 3° of each other's calculations.

General Illustrations of the Solar System.

Having now concluded an account of the planets in detail, we shall endeavour to illustrate them as parts of one great system, and give some idea of their *relative* magnitudes, distances, etc.

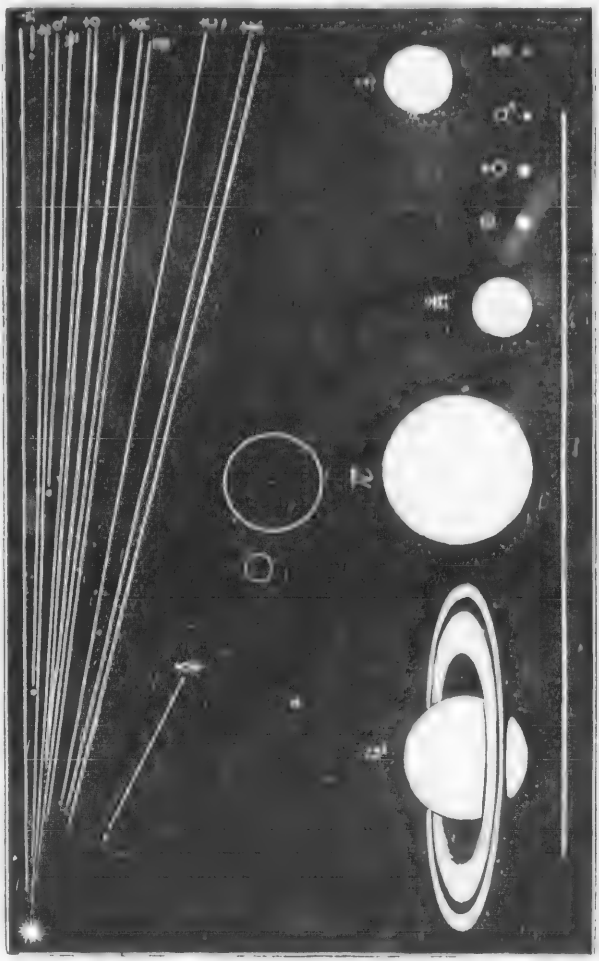
617. "Choose any well-levelled field or bowling-green. On it place a globe, two feet in diameter; this will represent the sun; Mercury will be represented by a grain of mustard seed, on the circumference of a circle 164 feet in diameter for its orbit; Venus, a pea, on a circle 284 feet in diameter; the Earth, also a pea on a circle of 430 feet; Mars, a rather large pin's head, on a circle of 654 feet; Juno, Ceres, Vesta, and Pallas, grains of sand, in orbits of from 1000 to 1200 feet; Jupiter, a moderate-sized orange, in a circle nearly half a mile across; Saturn, a small orange, on a circle of four-fifths of a mile; Uranus, a full-sized cherry, or small plum, upon the circumference of a circle more than a mile and a half; and Neptune, a good-sized plum, on a circle about two miles and a half in diameter. As to getting correct notions on this subject by drawing circles on paper, or, still worse, from those very childish toys called orreries, it is out of the question. To imitate the motions of the planets, in the above-mentioned orbits, Mercury must describe its own diameter in 41 seconds; Venus, in $4^{m.}\ 14^{s.}$; the Earth, in 7 minutes; Mars, in $4^{m.}\ 48^{s.}$; Jupiter, in $2^{h.}\ 56^{m.}$; Saturn, in $3^{h.}\ 13^{m.}$; Uranus, in $2^{h.}\ 16^{m.}$; and Neptune, in $3^{h.}\ 30^{m.}$"—*Sir John Herschel.*

To this it may be added, that owing to the inclinations of their orbits to the plane of the ecliptic, the objects representing the planets, in the above illustration, ought to be some a little above, some a little below the level of the ground, and some just on it, or with one half above, the other half below the surface of the ground—the planet being then in its nodes. The *greatest elevations above or depths below the ground* attained in the above example would be, 10 feet for Mercury; 8 feet for Venus; 10 feet for Mars; 128 feet for Hebe (14° 47′); 284 feet for Pallas (34° 37′); 23 feet for Jupiter; 87 feet for Saturn; 52 feet for Uranus; and 183 feet for Neptune. Thus, all the planets, excepting Juno, Hebe, and Pallas, would circulate near the level of the ground; 87 and 183 feet, the greatest distances of Saturn and Neptune from the level of the ground, being little in comparison with their distances from the sun—two-fifths of a mile, and a mile and a quarter.

618. The following woodcut (Fig. 52) will give an idea of several important particulars regarding the planets. The white line at the *right* (looking at the figure in the way in which the book is held for reading) is intended to represent the sun's radius

or semidiameter; and the figures next it represent the magnitudes of the planets, in proper proportion to the sun's semi-

Fig. 52.



diameter and to each other, in the following order: Saturn, Jupiter, Uranus, the Earth, Venus, Mars, Mercury, Neptune, with their signs. The circular outlines in the middle of the

figure represent the relative magnitudes of the earth and moon. The lines and characters at the *left* side of the figure are designed to show the relative distances of the planets from the sun, and the inclinations of their orbits to the plane of the ecliptic. The sun is represented at the left-hand lower corner. The dots at the ends of the white lines nearest to the sun, represent the planets at their proportionate distances from the sun, the signs of the planets being at the other ends of the white lines. The distance of Neptune from the sun would be represented nearly by a line from the sun to the opposite corner of the figure—being about half the distance of Uranus further from the sun. To obtain a proper idea from the figure of the inclinations of the orbits of the planets to the plane of the ecliptic, the book should be turned sideways so as to place the line representing the sun's radius at the top of the figure. Then, the lowest line, stretching out to the left of the sun will represent the plane of the ecliptic, and the other lines the planes of orbits of the various planets. It will be observed how near the orbits of the planets Uranus, Jupiter, Mars, Saturn, and Venus, are to the plane of the ecliptic; and Neptune's orbit should be represented between the lines of the orbits of Mars and Jupiter. Thus, the orbits of none of the large planets are inclined to the Earth's orbit more than 3° 23′, the inclination of Venus's orbit. The inclination of Mercury's orbit is seen to be considerable (7°); but the furthest removed from the general level (so to speak) are the orbits of the asteroids, some of which have an inclination of from 24 to nearly 35 degrees; as for example, Pallas (34° 42′), Euphrosyne (26° 25′), Niobe (23° 19′), Phocea (21° 34′).

619. The following tables—originally constructed by C. Piazzi Smyth, Astronomer-Royal for Scotland, and recently revised by him for the new edition of Mackay's "Manual of Modern Geography" (Edinburgh, *W. Blackwood & Sons*, 1873)—give in detail all the most important discoveries hitherto made by astronomers relative to the sun, moon, and planets. On comparing them with the corresponding tables in former editions of this work, it will be seen what immense progress our science has made during the last fifteen years. In particular, the great physical problem of the age—*the true mean distance of the sun* from the earth—has made rapid progress towards solution. That distance, it may now be confidently affirmed, is *not* 95,000,000 miles, but 92,093,000; for that is at

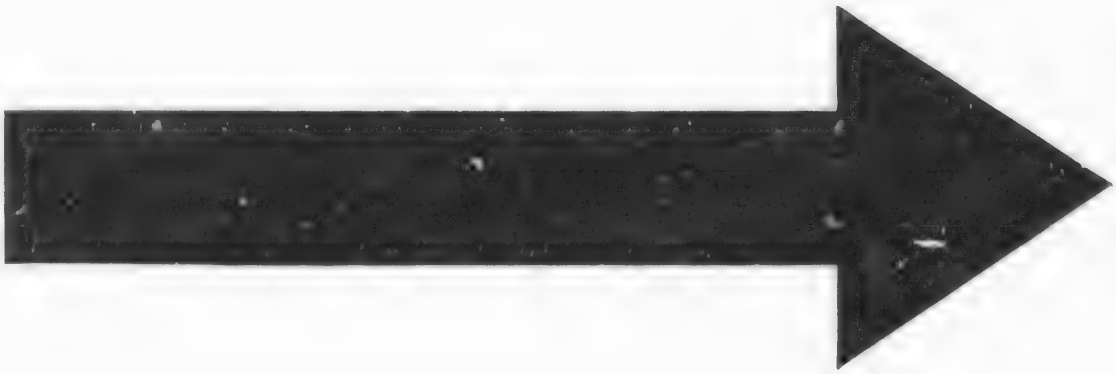
once the grand mean of all recent researches, as also the distance clearly indicated by the Great Pyramid of Jeezah, which, as if planned by supernatural wisdom, anticipates so many of the cosmological discoveries of modern science, though erected upwards of 4000 years ago.

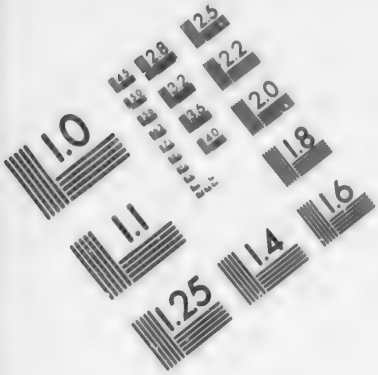
THE SOLAR SYSTEM.

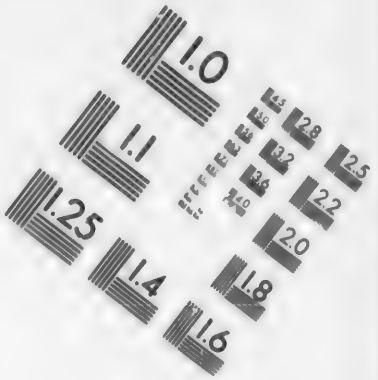
Name of Body.	Mean Distance from Sun in Miles.	Time of Revolution in Mean Solar Days.	Velocity in Orbit per hour in Miles.	Time of Rotation on Axis.	Annual ∥ of Light, Earth =	No. of Moons.
				d. hr. m.		
Sun	...	...	17,583	25 7 48	...	...
Vulcan	13,082,000	19·70	174,000	...	...	...
Mercury	35,649,000	87·97	105,330	1 0 5	6·656	0
Venus	66,614,000	224·70	77,050	23 21	1·932	0
Earth	92,093,000	365·25	65,593	1 0 0	1·000	1
Mars	140,322,000	686·98	53,090	1 0 37	·436	0
The Asteroids.	250,000,000	1,684·74	39,882	...	·130	0
Jupiter	479,141,098	4,332·62	28,744	9 55	·036	4
Saturn	878,461,000	10,759·30	21,221	10 29	·011	8
Uranus	1,766,565,000	30,686·82	14,963	9 30	·003	4
Neptune	2,766,133,000	60,126·71	11,958	...	·001	1

Name of Body.	Polar Diameter in Miles.	Equatorial Diameter in Miles.	Volume or size, Earth = 1.	Mass or Weight, Earth = 1.	Density or specific gravity, Earth = 1.	Force of gravity at surface, Earth = 1.	Inclination of Planet's Equator to plane of Orbit.
Sun	852,380	852,584	1,245,130·000	314,760·000	·25	27· 2	0° 0′ 0″
Vulcan	7857	7857	...	...	...	...	...
Mercury	2,962	2,962	·052	·070	1·24	1·15	...
Venus	7,510	7,510	·851	·790	·92	·91	49 58 0
Earth	7,899	7,925	1·000	1·000	1·00	1·00	23 27 24
Mars	4,036	4,920	·139	·120	·96	·50	28 51 0
The Asteroids	670*	670*	...	...	...	...	...
Jupiter	83,151	88,400	1,387·431	300·860	·22	2·45	3 4 0
Saturn	64,714	71,904	746·898	90·030	·12	1·09	26 49 0
Uranus	29,722	33,024	72·359	12·640	·18	1·05	76 0 0
Neptune	36,620	36,620	98·664	16·760	·17	1·20	26? 0 0
Moon	2,158	....	·024	·013	·63	·17	...

* Pallas, the largest of them.







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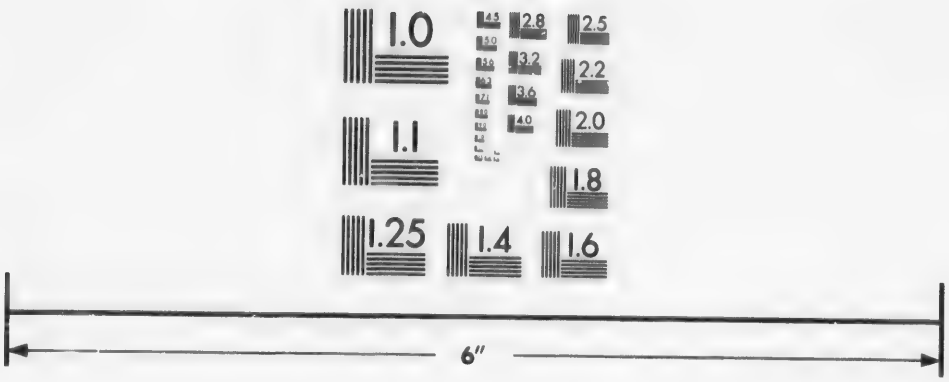

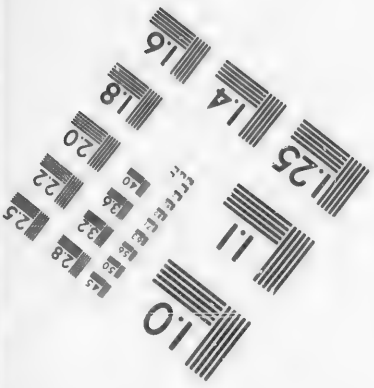

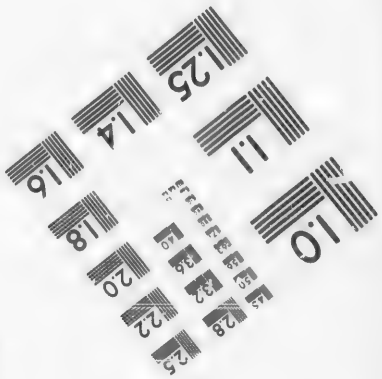

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Comets.

620. The comets are those stars which appear at times in various parts of the heavens, describing an apparently irregular course when compared with the planets; approaching very near to the sun, and again receding to a great distance from him and disappearing.

621. Comets appear under very various aspects. Usually, there is a brilliant luminous point called the *nucleus;* and a more diffuse light surrounding the nucleus, called the *coma* or hair. These two constitute the *head;* and there is often present, though not always, a long luminous appendage, called the *tail.* The tail is generally turned in a direction *from* the sun: and frequently is bifurcated, that is, divides into two branches, sometimes into more. Occasionally it is bent into a gentle curve. Some comets have several tails, that is, streams of light diverging from them; and many small comets are without any such appendage.

622. The comets are considered to be masses of highly-heated, self-luminous vaporous matter, or solid nuclei surrounded by much gaseous matter, revolving round the sun in very elongated ellipses, so that at one time they are very near the earth and sun, and at another time very remote from these orbs. But the existence of a solid nucleus is by no means established.

623. The tails of the comets vary considerably in magnitude. The tail is often scarcely perceptible at first, enlarges as the comet approaches to the sun, is most developed just after it has passed its perihelion; and gradually diminishes as the distance from the sun increases, and the influence of that body lessens. The tails of some comets have been estimated at upwards of 100 millions of miles in length—that of the comet of 1843 at 200 millions of miles. Some have had the extremities of their tails in the zenith, while they themselves were in the horizon. From the above phenomena,

it has been conjectured that the tail of a comet is formed of matter ejected from its body by the sun's heat.

624. The comets revolve in extremely eccentric orbits. The great comet of 1680 was calculated to have approached within about 150,000 miles of the sun,—about one-sixth of his diameter.

625. The periods in which several of the comets revolve round the sun have been computed, and the correctness of the calculation proved by the return of the comet several times. A very bright comet was recorded to have been seen in the years 1531 and 1607. In 1682, a comet appeared, which was observed by the celebrated astronomer **Halley**, and calculated by him to be the same which had been seen in 1531 and 1607 (and which might be traced back to the year 11 B.C., and is supposed identical with the comets of 1305 and 1456). He accordingly predicted its return in about 1758, computing it to have a period of between seventy-five and seventy-six years. It did appear, to the great delight of the astronomical world, in 1759, nearly about the assigned period; its delay being caused, as predicted by **Halley** and correctly calculated by **Clairault**, by the action of Jupiter and Saturn upon it. This comet again, in 1835, returned at the calculated time (28,105 days), and followed very nearly the course among the stars predicted for it. It remained visible, by the aid of the telescope, from August 1835 to May 1836; and was very bright when crossing among the stars of the Great Bear. In 1682, the tail of this comet stretched over a space of 30°. It is expected again about the year 1910. The great comet of 1680 has been conjectured to be identical with the comets of 43 B.C., 575 A.D., and 1105 A.D., having a period of about 575 years. A brilliant comet with a very long tail, which appeared in the year 1264, is supposed to have been the same which was seen in 1556. If so, it must have a period of about 300 years; while the great comet

of 1811 is supposed to have a period of about 3000 years.

626. The comet of **Biela** performs its revolution in the short period of $6\frac{3}{4}$ years (2413 days). It does not pass much beyond the orbit of Jupiter. The orbit of this comet crosses that of the earth, and we were within a month of encountering it in the year 1832. A remarkable phenomenon recently took place in this comet. Shortly after its second last appearance, between November 1845 and January 1846, it separated into two distinct comets, each with a nucleus and a short tail, which moved on together, as if independent, and still continued separate when the comet had run through one complete revolution in its orbit, and reappeared in 1852. The distance between the nuclei had then considerably increased.

627. A comet, with a period of about $7\frac{1}{2}$ years, was discovered in 1843 by **M. Faye**. The comet of **Encke** has a still shorter period, $3\frac{1}{4}$ years, or 1210 days. There are two other comets, **De Vico's** and **Brorsen's**, whose periods have been calculated—1993 and 2042 days.

628. The comet of **Encke** has led to some singular speculations regarding the existence of a fluid called *the ether*, supposed to be spread out through space. Its period of revolution round the sun is found to be diminishing. This is attributed to a resistance opposed to its progress by some material fluid through which it passes, which weakens its centrifugal force, gives the sun's attractive force greater proportionate power, enables that body to draw it into a smaller orbit, in which it moves more rapidly, and therefore runs through its course in a shorter time.

629. Some comets have been so exceedingly bright as to be visible in daylight. This was the case with the great comets of 43 B.C., 1402, 1532, and 1843, A.D.

630. The number of comets which circulate in the solar system is supposed to be very great,—perhaps

thousands. Some 800 have been recorded; and it is believed that the proportion of comets which are visible to us must be greatly under the number which really exist.

631. Comets appear in all parts of the heavens, move in all directions, and with very different degrees of velocity. They are not, like the principal planets, confined to the zodiacal belt.

632. Comets are considered to be mostly, if not entirely, in the aerial state, for the following reasons. The stars, even those of very small magnitude, can be seen through their substance. They have been found to cause no sensible derangement in the motions of the satellites of Jupiter near to which they have passed, while they themselves have been considerably influenced and diverted from their course by the latter—indications that their mass is small, and therefore, as their bulk is considerable, that they are in the aerial state. Also, they present no *phases*, which seems to show that light is reflected from every part of the comet, and hence, that the sun's light penetrates their substance, which indicates an aerial state.

633. In ancient times, comets were supposed to resemble planets, and, like them, to go through certain revolutions in regular periods. But from the commencement of the Christian era to the time of **Tycho Brahe**, they were generally regarded by astronomers merely as meteors, existing in the atmosphere. He found that their distances were beyond that of the moon; and the idea that comets are at considerable distances, and revolve round the sun in regular periods, was confirmed by **Kepler, Hevelius, Dorfel, Newton, Halley**, and others.

The Zodiacal Light.

634. This is a faint luminosity in the sky, visible in the west, immediately after twilight in spring; and in the east, towards the close of autumn, just before sunrise. It is very distinct in tropical regions, and is particularly described by Humboldt, who speaks of "the

mild radiance with which the zodiacal light, shooting pyramidally upwards, illumines a part of the uniform length of tropical nights." He states that in his voyage from Spain to South America, "the strength of the light—it might almost be called illumination—increased surprisingly the more I approached the equator in South America and the South Sea. In the continually dry, clear air of Cumana, in the grass steppes of Caraccas, upon the elevated plains of Quito and the Mexican seas, especially at heights from eight to twelve thousand feet, the brightness sometimes exceeded that of the most beautiful sparks of the Milky Way."—*Cosmos*, vol. iv. It has been supposed to be a vast nebulous ring revolving between the orbits of Venus and Mars; but, within the last few years, some curious particulars have transpired, which would seem to show that that theory must now be abandoned. In 1855, the Rev. G. Jones, chaplain of the U. S. steam-frigate "Mississippi," narrates the following: "I was fortunate enough to be twice near the latitude of 23° 28′ N., when the sun was at the opposite solstice, in which position the observer has the ecliptic at midnight at right angles with his horizon, and bearing east and west. There I had the extraordinary spectacle of the zodiacal light simultaneously at both east and west horizons, from 11 to 1 o'clock, for several nights in succession. It seems to me that this can be explained only on the supposition that the zodiacal light is a nebulous ring having the earth for its centre, and lying within the orbit of the moon." *

The Meteoric Systems.

635. Meteors have been noticed traversing the sky in all ages, and at all parts of the earth's surface. Many of them have been attended by the actual fall of

* "Descriptive Astronomy," by G. F. Chambers. Oxford, 1867.

some substance or body, to which the names of *aerolites* and *meteoric stones* have been applied. When the body explodes into small fragments before reaching the earth, the fragments are termed *fire-balls*, and sometimes *bolides;* and when the fragments are apparently consumed whilst traversing the upper regions of the atmosphere, they are known as *shooting-stars*. Many ingenious theories have been devised to account for these remarkable phenomena. But it is now generally supposed that they consist of small fragmentary masses, revolving in extremely eccentric orbits round the sun, some of which, coming within the sphere of the earth's attraction, are precipitated on its surface; the intense heat and explosion being caused by the action of the atmosphere on bodies passing through it at a very high velocity. Other planets of the solar system, especially the remoter ones, pass through similar rings of meteors, and, like the earth, attract multitudes of them to their surfaces; while, doubtless, the sun himself, owing to his superior gravitating power, attracts inconceivable numbers of them, precipitating them with tremendous momentum on his own surface; thus providing inexhaustible materials for maintaining his incessant light and heat, with which he vivifies and blesses our universe.

636. Two remarkable circumstances in the history of shooting stars render it almost certain that they are of a planetary nature—their periodical recurrence at certain times of the year, and their divergence from certain fixed points in the sky. A brilliant display of falling-stars has been observed in many years to occur between the 12th and 14th of November; and a less numerous shower, very often about the 10th of August. The meteors of November appear to diverge from a star in the constellation Leo,—those of August from a star in the Camelopard, or the vicinity of Algol, in Perseus,—whatever may be the elevation of these stars above the

horizon. "During the celebrated fall of shooting-stars, on the night between the 12th and 13th of November 1833, the fire-balls and shooting-stars all emerged from one and the same quarter of the heavens, namely, in the vicinity of the star γ in Leo, and did not deviate from this point although the star changed its apparent height and azimuth during the time of the observation. Such an independence of the earth's rotation shows that the luminous body must have reached our atmosphere from without."—*Cosmos.* Astronomers have determined that the orbit of each member of the November star-shower is an elongated ellipse, having its perihelion lying on the earth's orbit, and its aphelion beyond the orbit of Uranus; that the time of revolution of each member of the ring is $33\frac{1}{4}$ years; that the inclination to the earth's ecliptic is 17°; and that the motion is not *direct*, as in the case of the planets, but *retrograde*. The August meteors, again, travel in a path so eccentric, that near the earth's orbit it is almost parabolic. Its period, like that of the comet of 1862, with which it seems closely associated, is 145 years; while its aphelion distance is about twice the distance of Neptune.

637. The periodical occurrence of meteors arises from their circulating round the sun in broken rings, in orbits near which the earth is at the periods when the meteors are seen. There may be several planetary masses having the same orbit, following each other at certain intervals, and crossing near the earth's orbit, so that they become visible at certain times,—"a stream of meteors in their progress of circulation round the sun." This supposition would also explain their appearance of diverging from one point in the heavens.

638. Upon an average, about seven shooting-stars of every description may be seen at any one spot every hour on clear nights. In the August shower of 1842, one observer saw 34 in ten minutes. In 1852, on the

10th of August, the writer saw 27 in half-an-hour. It has been roughly calculated that the average number of meteors which traverse our atmosphere daily, and that are visible to the naked eye, does not fall short of 7,500,000. So far as observation has yet gone, these are divisible into 56 distinct groups, pursuing their courses in 56 different orbits, and having as many radiant points in the celestial sphere. Having highly eccentric orbits, their velocities are very different in different parts of their paths. When in their perihelia, some of them travel at the rate of 200 miles per second, but their average velocity does not exceed 34 miles per second, being nearly twice the average velocity of the earth in her orbit. Shooting-stars usually become visible to the naked eye at a height of 72 miles, and again disappear at a height of 52 miles. Some are composed mostly of metallic *iron* always alloyed with *nickel*, and small quantities of other metals, as cobalt, copper, tin, and chromium. In the main, they are composed of metallic iron and various compounds of silica, the iron forming in some cases as much as 95 per cent. Among the silicates may be mentioned olivine, a mineral found abundantly in volcanic rocks, and augite.

PART IV.

PARALLAX, ABERRATION, AND PRECESSION.

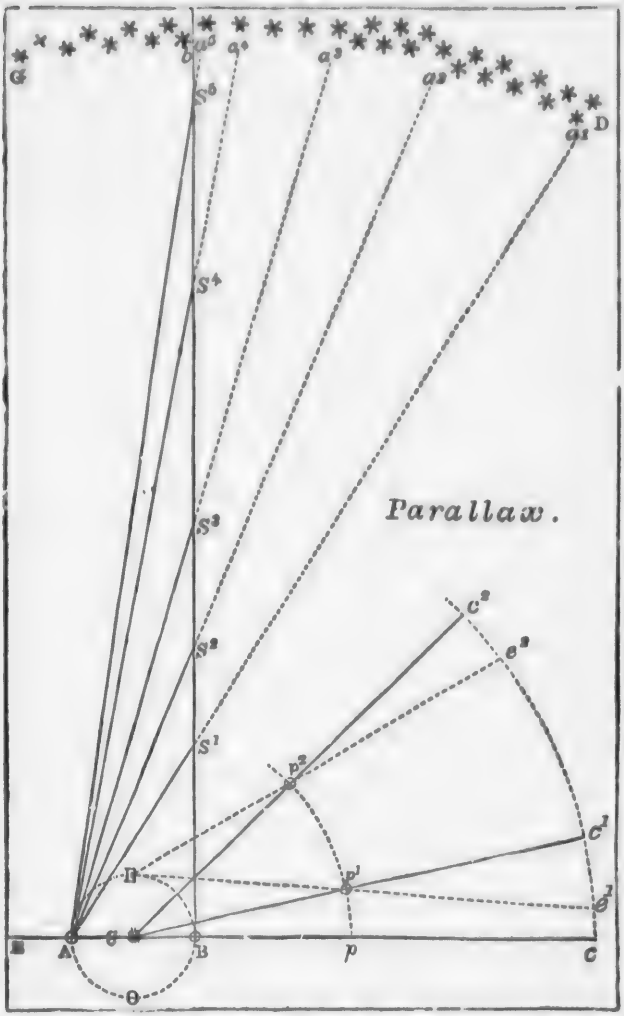
SECTION I.

Parallax.

639. The word Parallax is used in Astronomy in two senses; a special and a general sense. In the special sense, parallax signifies the difference in the altitude of a celestial body as seen from a point on the surface of the earth and from the centre, if it could be seen from that place. This is sometimes termed the *diurnal parallax.*

640. This will be illustrated by the following figure (53): Let the dotted circle A E B O be the earth; p, p^1, and p^2 any heavenly bodies; and the dotted arc at the right, $c\ c^2$, the imaginary surface of the heavens to which we refer the positions of celestial objects. Let E be the position of an observer on the earth's surface. Now, if the heavenly body p^2 be viewed from E, it will appear at e^2 on the surface of the heavens, as shown by the dotted line E p^2 e^2; but if viewed from C, the earth's centre, it would appear at c^2, as shown by the line C p^2 c^2. The difference of these two positions is the arc c^2 e^2, which is therefore termed the parallax at E of the body p^2; or, instead of the arc c^2 e^2, the angle c^2 p^2 e^2, which the arc c^2 e^2 subtends, and which is of the same number of degrees (73-5), and may be called the parallax of p^2 at E. Or, the angle E p^2 C, which is equal to the angle c^2 p^2 e^2, may be called the parallax of p^2 at E. The latter is what is usually stated as the parallax of the object. Thus the parallax of a celestial body is the angle at it formed by two straight lines, one drawn to it from the earth's centre, the other from the observer's position on the earth's surface.

Fig. 53.



641. The effect of parallax is to depress the body, always making it appear nearer to the horizon, as seen

from the surface, than when seen from the centre. This is evident, as c^2, the position of p^2 as seen from the centre, is nearer the zenith of E than e^2, its position as seen from E.

642. Parallax is always greatest when the body is *in* the horizon, and greater as the body is *nearer* to the horizon of the observer. This is evident from the preceding figure, in which the paraliax, $c^2\ e^2$ of p^2, is less than $c^1\ e^1$, the parallax of p^1, which is nearer to the horizon of E than p^2.

643. There is no parallax of a body in the zenith. This is evident from the preceding figure, in which the body p, which is in the zenith of an observer at B, appears in the same position in the heavens, c, whether viewed from B or from the centre.

644. As bodies must appear in different positions when viewed from different points of the earth's surface, it is desirable, for astronomical and nautical purposes, to calculate their apparent positions in reference to some fixed point; this being known, a correction can be applied for the difference in the apparent position as seen from the surface, and that given as the position seen from the fixed point. The point selected for this purpose is the earth's centre, and the ordinary meaning of parallax, therefore, is the difference in the positions of a body as seen from the earth's surface and from the earth's centre.

645. Parallax, in the wider acceptation of the term, signifies the apparent change of position in an object arising from a change in the position of the observer—sometimes termed its *parallactic motion*. As in the above case, it may be expressed by *the angle formed at the object by two straight lines drawn from the object to the two points from which it is observed.*

646. When an object is viewed from two different points, it will appear in different directions at these points. And the exact amount of difference will be

expressed by the angle at the object formed by the two lines of view (640). Thus, in Fig. 53, if A and B in the dotted circle below represent two positions from which the object S^1 is seen, that object will be seen in the direction A S^1 from A, and B S^1 from B. The angle A S^1 B will be the amount of difference of the directions A S^1 and B S^1, or the parallax of S^1.

647. The parallax of any object diminishes as its distance increases; and a body may be so remote that its parallax will become so small as to be insensible.

648. This is illustrated by Fig. 53. Let A and B be two points from which the bodies S^1, S^2, S^3, S^4, S^5, are viewed. As the distance increases the angle at the body diminishes, A S^2 B being less than A S^1 B, and A S^3 B being less than A S^2 B, and so on. It is evident that if the distance from the line A B were very much increased, the angle at the body would disappear altogether, the lines to it from A and B would coincide, and the distance from A to B would be as nothing compared with their distance from the object.

649. Now, it is by means of the parallax of a heavenly body that its distance is calculated. The distance between the two points being known, and the angle of its parallax, trigonometry furnishes the distance from the position to the object.

650. The parallax of any body increases as the distance between the points of view increases. This is evident; for if the observer at B were to shift his position to the right till he came to *c*, then the angle A S^3 B would be very much increased, as the line from S^3 to B would now be in the direction from S^3 to *c*; and thus a body too far distant to give a perceptible parallax at two points might give a very sensible parallax if the distance between the two points of view were very much increased.

651. Now, none of the fixed stars give any parallax with the radius of the earth; it is therefore known that

their distance is infinite when compared with that radius, and that with it alone we have no means of measuring the distance of a fixed star. Therefore a much longer basis has been tried—the longest which we can command—the radius of the earth's orbit. But few of the fixed stars give any parallax even with this extended basis: the most of them have no *annual parallax* as it is termed: the earth's orbit sinks to nothing compared with the enormous distances of these glittering points; and with respect to the greater number of the fixed stars we have no means of ascertaining their distance. See Part VI., on the Fixed Stars.

652. That distant objects give no parallax with points near each other is very obvious in the case of any short distances on the earth with the moon. For example, looking at one limb of the moon along two parallel streets, it will be found to appear in the very same direction along either street. The angle of parallax is too small to be discernible; the two lines from the street to the moon coalesce; the distance between the two points of observation is a mere point compared with their distance from the moon; and we could not, with that distance as a basis, measure the moon's distance. The same may be observed of an object on earth. If an individual walk along a road for any given distance, and take some very remote object, such as the stars or a far-off tower or mountain, whereby to judge of the apparent motions of bodies between his line of motion and the fixed objects by which he judges of their apparent motions, he will find that these various bodies will have shifted their apparent position less and less according as they are further from him—that is, their *parallax* will be less. In proportion as they are more remote, he will find the angle at the body, formed by two straight lines drawn to the two points of view, become less and less till it disappears and the two lines coalesce; then there is no parallax, and with that basis *no means of measuring the distance of the object.*

SECTION II.

Aberration.

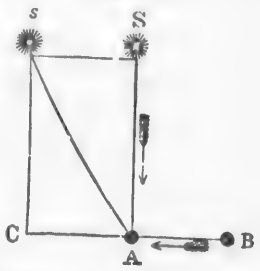
653. **Aberration** is an *apparent displacement* of the celestial bodies from their true position, arising from

the motion of the earth in its orbit, and the time required by light to traverse space.

654. Every object is seen in the direction which the rays from it have when they strike the eye, *if the eye be at rest.* But if the eye be in motion, the direction in which the object is seen will be one compounded of the direction of the eye's motion and that of the rays from the object. The difference between the real direction of the object and that in which it appears is called the **aberration.**

655. Let A, Fig. 54, be the position of an observer, and S the position of a star. Let B be the situation of the earth, when that ray emanates from S, by which the star is seen at A,—the earth and ray coming to A at the same instant. Then, by the composition of motion, the star, when the earth comes to A, will appear at *s*, in advance of its true position. The angle S A *s* is the aberration. As S A, which represents the motion of light, is very great compared with B A or A C, which represents the earth's motion in the same time (as 185,000 to 18), the aberration is very small.

Fig. 54.



656. The aberration is greatest when (as in Fig. 54) the direction of the ray is perpendicular to the direction of the earth's motion: in this position there is a displacement, by abberration, to the extent of 20·5″ (twenty seconds). It diminishes from this till the directions of the two motions are parallel, when it ceases altogether. There is also some aberration from the motion of the parts by the earth's rotation; but this is insensible.

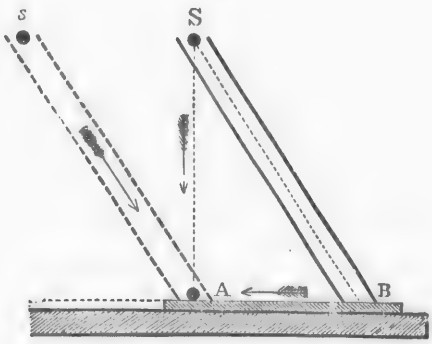
657. Had the earth been stationary at A, or had light come instantaneously from S to A, the star would appear in its true position at S. The phenomenon of

aberration is one of the most convincing proofs of the earth's motion round the sun; and it confirms very satisfactorily **Roemer's** discovery of the progressive motion of light, and also the rate of its motion as inferred from the eclipses of Jupiter's satellites, and determined by M. Foucault in 1862 by a rotating mirror.

658. Aberration may be illustrated by the manner in which drops of rain strike upon an individual, according as he is in motion or at rest. If the drops fall perpendicularly, and he be at rest, they will be felt only on his head—that is, *they will strike in the direction of their own motion.* But if he be moving quickly, they will strike upon his face, and *appear to be coming in a slanting direction towards him*, as if they fell from a point not only *above* him but in *advance* of him. It is evident that the direction in which they would appear to come must depend upon the *real directions* and *comparative velocities* of the two motions.

659. Or, if we conceive a ball to be let fall in the direction S A, Fig. 55, and to enter the tube S B, which has a motion

Fig. 55.



in the direction B A sufficient to carry it to the position A *s* in the same time in which the ball would fall from S to A; then the ball would, while passing from S to A, move in the axis of the tube (not touching the sides), and to an observer at the bottom of the tube would necessarily appear to have come from *s*, not from S, and to move in the direction *s* A, not S A. The ball is analogous to the ray of light, the bottom of the tube

to the earth, and the direction in which the ball appears to move to the direction in which the star is seen.

660. Besides the aberration of the fixed stars, there is also an aberration of the planets and comets, arising from their motion. When a ray of light from a planet arrives at the earth, its direction does not show the true position of the planet; as the latter has made a certain progress in its course since that ray left it—and its true position must be in advance of its apparent position. For the discovery of the aberration of light, and determination of its amount, science is indebted to the distinguished English astronomer **Dr Bradley** (in 1728).

SECTION III.

Precession of the Equinoxes—Nutation of the Earth's Axis.

661. Besides its rotation on its axis, the earth has two other motions which change the direction of the parts without altering the position of the whole in space, called *Precession* and *Nutation*. These motions are very slow, and are not discoverable except by very careful and long-continued observation.

1. Precession of the Equinoxes.

662. The ecliptic cuts the equinoctial in two points, called the **equinoxes,** during one revolution of the earth round the sun. But **these two great circles cut each other in different points each year;** that is, the points (or stars) in the starry heavens where they intersect are different each year. This change in the position of the equinoxes is called *the precession of the equinoxes.*

663. The line of the equinoxes moves backwards*

* A motion from west to east, or in the order of the signs, is said to be *direct;* from east to west, or against the order of the signs, *retrograde* or *backwards.*

upon the ecliptic, that is, from *east* to *west*, or in a direction contrary to the sun's apparent annual course through the ecliptic, which is from west to east; so that each year the sun crosses the equinoctial in a point *west* of that in which they last met. The amount of this retrocession is 50·21″ yearly.

664. As the sun moves eastward through the ecliptic, and the equinox moves westward, the sun will come sooner to the equinox in each revolution, for they move round towards each other; hence the period of each equinox will come a little earlier every year; from which the expression *precession of the equinoxes* is derived. The time which the equinox precedes each year is $20^{m.}\ 20^{s.}$, that being the time in which the sun goes through an arc of 50·21″.

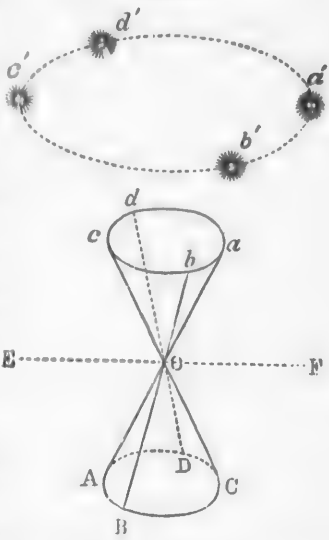
665. From this circumstance, the positions of the signs of the zodiac among the stars change regularly backwards (in the opposite direction to the sun's motion). The rate at which the equinox recedes is such, that it makes a complete revolution round the ecliptic in 25,898 years. This is equal to 1° in 71·6 years, or 30° (one sign) in about 2000 years. And accordingly it is found that the position of the equinox is now about 30° behind what it was 2000 years since: then, the *signs* and *constellations* of the same name were the same,—but each sign, which still retains the name it had then, is now in the preceding constellation.—See Par. 114.

666. From this recession of the equinox, the true year, or the period of the earth's return to the same star, is a little longer than the equinoctial or tropical year, which is the interval between two returns to the same equinox.—See Par. 330.

667. This precession of the equinoxes is caused by a *conical motion of the earth's axis*, by which, while the middle point remains fixed, the poles describe a small circle, as in the following figure. Let A *a*, B *b*, C *c*, D *d*, represent the earth's axis, O being the middle point. It does not always remain in the

same direction, pointing to the star a',—but shifts on its centre, passing from A a to B b, etc., the poles describing the circles A B C D, a b c d, and successively pointing to the stars a', b', c', d'. Thus, each radius describes a cone — completing it in the long period of 25,898 years. The radius O A describes the cone O A B C D,—the radius O a, the cone O a b c d.

Fig. 50.



668. The motion of each radius exactly resembles that of a top spinning. It is often observed, besides its rotatory motion, to have a swinging motion, inclining to one side, then gradually shifting, and inclining as much all round, so that its axis has a compound motion, turning like any revolving body, and at the same time describing a cone of which the apex is at the ground. In this swinging motion, it always keeps the same inclination to the horizon, as the earth's axis does to the ecliptic.

669. From this, the pole of the heavens (the point in the heavens towards which the earth's pole is directed) describes a circle round the pole of the ecliptic; this circle is always 23° 28′ from that pole.

670. Hence the earth has not always the same star for its pole-star.* The present pole-star is 1° 24′ from the pole; at the time of **Hipparchus** (about 140 B.C.) it was about 12° from the pole. It will be nearer to the

* The brightest star near the pole of the heavens is the pole-star at the time. At present this star is Polaris in the constellation Ursa Minor. At the time of the erection of the Great Pyramid (B.C. 2170), it was the star Alpha Draconis. See "Facts and Dates" (p. 128), Blackwood & Sons, 1870.

pole still for a little, and then will recede from it again; and in about 12,000 years the pole of the heavens will be on the opposite side of the pole of the ecliptic, 46° 56′ from its present position, and very near **Vega**, the principal star in the constellation **Lyra**, which star will then serve for a pole-star. See Fig. 56, in which the axis is seen pointing successively to the different stars a', b', c', d' in the sphere of the heavens.

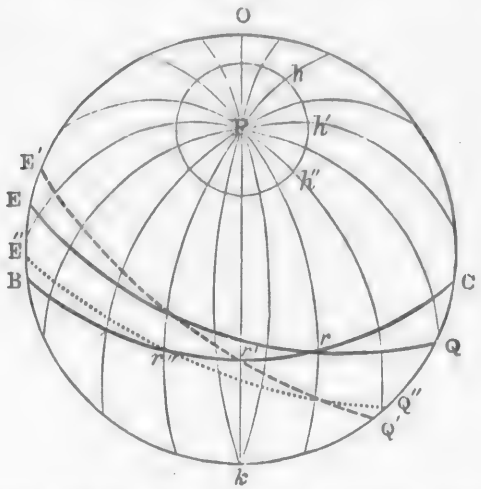
671. But the angle of inclination of the axis to the ecliptic always remains unchanged; so that the angle between the planes of the ecliptic and equinoctial still continues the same—23° 28′. And the whole earth partakes of this motion, so that the axis and poles still bear the same relative position to the other parts of the earth's surface; the latitudes remain the same, and the waters are unaffected.

672. From this, then, the points where the ecliptic and equinoctial cut each other must be continually shifting. This will be illustrated by the following figure. Let P represent the pole of the ecliptic, the sphere representing the sphere of the heavens. Let B C be the ecliptic, and the small circle h h' h'' the circle in the heavens marked out by the earth's pole round the pole of the ecliptic, and the points h h' h'' on that circle different positions of the pole of the heavens. When h is the pole, the equinoctial will be E r Q, intersecting the ecliptic in r. When h' is the pole, E′ r' Q′ will be the equinoctial, cutting the ecliptic in r'—and when the pole is at h'', the position of the equinoctial will be E″ r'' Q″, having r for the equinox

673. The cause of this conical motion of the earth's axis is the action of the sun and moon upon the protuberant matter at the earth's equator. As they move in the ecliptic, and the projecting matter at the equator is out of the plane of the ecliptic, their action tends to draw this towards the plane of the ecliptic and to make the planes of the ecliptic and equator coincide. But

the rotation of the earth on its axis prevents any change in the inclination of the equator and ecliptic;

Fig. 57.



and causes the earth to have the gyratory motion in its axis which gives rise to precession.

674. The amount of precession caused by the action of the sun is about 15·21″; that produced by the moon 35″, or nearly as 2 to 5.

2. Nutation.

675. The circle which the earth's pole describes round the pole of the ecliptic is not a true circle, but waved or undulating, as represented in the adjacent figure. This oscillatory motion of the pole backwards and forwards is termed **nutation**, being a sort of nodding motion of the earth's axis.

Fig. 58.

676. Nutation will be best understood by supposing

the point representing the *mean place of the pole* to describe the uniform circle round the pole of the ecliptic, while the *real position* of the pole describes a small circle (or rather ellipse) round the mean place.

677. This small ellipse is completed in a little less than nineteen years, at a distance from the mean place of the pole of about 9″—the longer axis of the ellipse, which points towards the pole of the ecliptic, being about 18·5″.

678. Nutation is caused by the action of the moon on the protuberant parts at the earth's equator, which, as the moon's orbit is inclined 5° 8′ 40″ to the ecliptic, and its nodes complete their revolution round the ecliptic in eighteen years seven months, causes the above described motion, accompanying that of precession.

PART V.

PROOFS.

679. Having now described the leading phenomena of the sphere of the heavens, of the earth, sun, and moon, and of the solar system; and having given the generally received explanations of these phenomena, it yet remains to render some account of the reasons by which it is proved that these are the correct explanations. There are three principal points to be proved: that the earth is round; that it rotates; and that it moves round the sun.

SECTION I.

The Earth is Round.

680. There is no scientific fact which can be established by a greater number of irresistible arguments than that the world we live on is round; and the greater number of these arguments are quite intelligible even to those who do not possess any mathematical knowledge.

681. (1.) Men have sailed round the world. A ship, starting from one place and sailing onwards, without ever turning back, merely moving a little to right or left to avoid running upon the land, *has come back to the place from which it set out.* This could only happen on a round body. It was first done by the expedition of **Magellan** (or Magalhaens) in the years 1518-21; afterwards by **Drake, Anson, Cooke,** and by great numbers of navigators recently. Magellan did not live to complete his voyage: he was killed in the Philippine

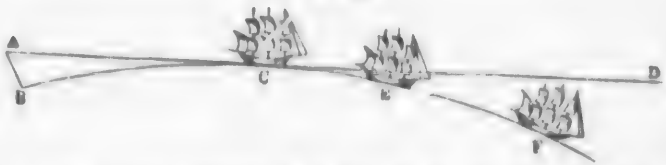
Islands, and his ships were brought back by one of his officers. But the Straits of Magellan, at the south of the American continent, and the singular nebulæ near the southern pole of the heavens, called the Magellanic Clouds, will preserve to distant ages the name of the leader of the first expedition that circumnavigated the globe. It was found, on their return to Spain, that the navigators had *lost one entire day* during their long, circuitous voyage. Had they circumnavigated the globe by sailing in the opposite direction, they would have *gained a day.* No more striking proof of the earth's rotundity could possibly be afforded.

682. It has also been well established that the world can be sailed round in shorter time, the further south the voyage is performed — as in the South Atlantic Ocean, beyond Capes Horn and Agulhas—which shows that its circumference narrows as we pass from the equator in a southerly direction; and, though we cannot sail round the world in the northern hemisphere, on account of the land and state of the north seas, the distance round can be very well ascertained by other means, and proves the same fact—the regular diminution of the thickness, or of the circumference of the earth, as we pass north or south from the equator.

683. (2.) When a ship sails from us, the lower part, the broad massive hull, first disappears; the slender top-masts and rigging go last out of view. And, if we look at it through a telescope, when it is too small and indistinct to be seen by the naked eye, we shall find that the highest parts of the masts are the last to disappear. Similarly, when a ship approaches, the upper parts come first into view. These things prove that the sea is not a flat plain, but that it bulges out between an observer and distant objects; that is, that it is convex. As similar appearances are observed at every part of the wide ocean, and on land too, where we can get an extensive flat piece or plain, it follows that the

world must be everywhere more or less round. See Fig. 59, in which a ship is represented sailing on a round surface, and at different distances from the observer.

Fig. 59.



684. At a distance of eight miles, two points, each ten feet above the sea or any extensive plain, are found to be invisible from each other, owing to the bulging out of the intermediate surface. The line joining them would be a tangent to the curved surface, just skirting its highest point. From this, by simple mathematical calculations, the diameter of the earth may be found; and it differs little from the diameter as found by methods capable of much greater accuracy.

685. (3.) When the sun rises, he does not give light to all the world at once: he shines on part only. He rises and gives light at any place sooner than at any other place further west. This may be easily ascertained even in Britain, which is so narrow from east to west; for the sun rises in that island *about one minute later for every ten miles farther west.* Aberystwith and Lowestoft are nearly east and west of each other, and about 240 miles distant; and the sun therefore rises about 24 minutes earlier at Lowestoft than at Aberystwith, which is 24 times ten miles west of it. Of this fact every one may easily convince himself by comparison of the times of sunrise, noon, or sunset, at places east or west of each other; and as the sun would evidently give light at once to the whole of any *flat plain* above the level of which he had risen, we have here a most convincing

proof that the world is more or less round in the direction from west to east.

686. (4.) If we admit the sun and moon we see from day to day during the whole course of our lives, to be always the same sun and moon, it follows from the phenomena of their rising and setting daily, that they have a way round the earth by passing under it; in fact, that they take many ways under it, as they rise and set at many different points of the horizon during the course of the year. From this it is plain either that the earth rotates daily, or that the sun, moon, and stars go daily round the earth—in either of which cases, the earth must be a body of limited extent towards the east and west, and more or less round in that direction.

687. (5.) As we pass further south, the pole-star and stars round it sink, till at the equator the former appears in the horizon, and disappears altogether if we go south beyond that line; while new stars come into view for every step we take south, till at the equator we command during one night a view of the whole of the stars of the heavens. As we can ascertain by simple measurements that the stars are at a very great distance from us, this regular change of elevation in any star as we pass north or south, and appearance of new stars and total disappearance of others, as we go south, show that we are moving along a surface that is more or less round from north to south. It is to be observed that the stars in sinking and then disappearing do not fade gradually in lustre, as if we were gradually increasing our distance from them, but remain equally bright to the last, showing that they are lost to our view from the interposition of something opaque between the star and the observer.

688. (6.) In eclipses of the moon, the earth's shadow always has a circular edge, and none but a round body can give a circular shadow in whatever position it may be placed. We know that eclipses of the moon are

caused by the intervention of the earth between the sun and moon; as, from time immemorial, these phenomena have never taken place except when the earth, sun, and moon are in one straight line—when the sun and moon are in exactly opposite parts of the sky; that is, in opposition.

689. (7.) The horizon, or *offing*, as it is sometimes called, is always *circular*, from whatever point we take it; its extent is greater, and the angle between the observer and its opposite points less, the higher the point from which we view it; and the *dip of the horizon* (the angle between a horizontal line as given by a spirit level and a line from the spectator to the actual horizon) is greater, the greater our elevation. All these, observed everywhere, give certain indications of a surface more or less round.

690. (8.) The lessening duration of twilight, as we pass towards the equator, gives distinct evidence of a spherical form in the earth, and of the various parts at the surface being further from the axis of rotation the nearer they are to the equator—whether we regard the earth, or the heavens, as performing the daily rotation by which the phenomena of sunrise and sunset are caused.

SECTION II.

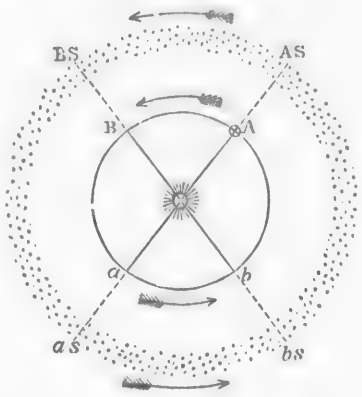
The Earth Rotates.

691. That the world turns daily on an axis, from west to east, making a complete rotation in about 24 hours, is well established by the following considerations:—

692. (1.) The whole sphere of the heavens appears to rotate from east to west in 24 hours; and we know

that this apparent motion can be perfectly explained by a rotatory movement of the earth in the opposite direction in the same time. Thus, in the adjoining figure, let the circle A B *a b*, represent any parallel of latitude on the earth (the sign of the earth at A and of the sun in the centre being disregarded); and let it be supposed that the earth rotates so as to bring A to B, the stary sphere B S A S remaining fixed. It is manifest that any one who was at A will, when at B, have come to a very different position as regards any object in the part of the starry sphere within his view, as B S. If he is not sensible of his motion, finding that any objects at B S are now in the position formerly occupied by those of A S, the former must have appeared to him to have moved from B S to A S, in a direction opposite to that in which he has moved,* and the whole starry sphere must appear to be moving round in the same direction. See par. 24, page 11.

Fig. 60.



693. (2.) The supposition of the daily revolution of the heavens is liable to this almost insuperable objection that, as the stars always, and the sun, moon, and planets, for the most part, preserve the same relative positions to each other during this great movement, a

* And opposite to that shown by the arrow at the top of the figure, which is there for a different purpose, as will presently be seen.

vast number of bodies, some of them much larger than the earth, very distant from us, and far distant and detatched from each other, must have one circular motion in common, in the same direction, each completing its circle in the same time, and the circles described by all being perfectly parallel to each other; an almost impossible series of coincidences, and the extreme impobability of which led to the absurd theory of crystal spheres. (See par. 22, page 10). This simple and *single* act of the earth's rotation on its axis affords an easy and natural explanation of these otherwise extraordinary and unaccountable coincidences in rate and direction of motion in so many different bodies.

694. (3.) The slower oscillation of the pendulum as we pass towards the equator—this diminution of the force of gravity being more than can be accounted for by the increased length of the pendulum from warmth, and by the spheroidal form—affords a strong presumption in favour of a rotatory motion of the earth, which, by the great centrifugal force it would generate at the equatorial parts, must lessen the force of gravity.

695. (4.) The spheroidal form itself affords an argument in favour of rotation, as we know that rotation tends to produce such a form. (5.) The analogy of the sun, moon, and planets, which are known by observation to rotate, affords a presumption that the earth also, which resembles them in so many points, has this motion

696. (6.) The easterly direction acquired by the great currents of wind that are constantly rushing from the cold regions of the earth towards the heated parts on each side of the equator, afford a strong argument in favour of a rotatory motion of the earth from west to east, which, by the great velocity of the equatorial parts compared with that of parts at a distance from the equator, imparts this easterly direction to the northern and southern currents. See Trade-winds.

697. (7.) A remarkable proof of the rotation of the earth from west to east is derived from the experiment of letting a pebble fall from the east side of the top of a very high tower; when it does not fall exactly at the bottom, as it would if it descended truly in the plumb line, but a little out from the bottom of the tower. This is inexplicable, except upon the supposition that the earth rotates; in which case, the pebble when at the top of the tower, being further from the axis of rotation than the bottom, moves in a larger circle, and therefore more rapidly, as the rotations of all the different parts are performed in the same time. Hence, while the pebble descends by the force of gravity, it also moves a little in advance of the lower parts of the tower by its greater velocity of rotation, and falls a little beyond the base. In short, it has a greater eastward tendency than the bottom of the tower, and must therefore, in falling, take a position a little in advance of it.

698. (8.) A very clear and satisfactory proof of the earth's rotation is afforded by the celebrated *pendulum experiment*, devised by M. Foucault. If a heavy body be suspended by a wire and made to vibrate (to oscillate backwards and forwards), *its vibrations will take place in the same plane*, even though the points from which it is suspended have a slow rotatory motion imparted to them. M. Foucault's pendulum was suspended from the dome of the Panthéon in Paris, and a fine point at the bottom of the weight was made to leave a mark in sand at each swing. The marks successively made in the sand showed that the plane of oscillation varied with regard to the building. Here, then, was a proof that the building, and therefore the earth, moved. If, at the pole of the earth, such a pendulum were suspended and set in motion, and a circle divided into degrees were placed beneath it, as the earth rotates in 24 hours, while the pendulum continues to vibrate in the same plane, the circle (attached

to the earth) would rotate, and bring the pendulum opposite to every successive degree till a complete revolution had been accomplished;—and as the earth's motion is not sensible to us, it would appear as if the pendulum had been continually changing its plane of motion in the opposite direction, making a complete revolution and returning to the original plane in 24 hours (or rather $23^{h}.\ 56^{m}.$ etc.). If made to vibrate in the plane of the meridian at other places, the same appearances would be caused by the earth's rotation; but the rate of apparent movement of the plane of vibration would gradually lessen as the place is nearer the equator, at which it would cease, as the circle would there cease to have any motion of rotation, and have no motion except what would be common to itself and the pendulum. It has been computed that the apparent motion of the plane of vibration would be about 15° hourly at the pole, 12·7° at Aberdeen, 11·5° at Paris, 9·7° at New York, 1·8° at Ceylon, and 0° at the equator; and as experiments made at many places coincide very closely with the calculated effects, we derive hence a very convincing proof that the earth rotates,—a means of ascertaining the period of its rotation (found to coincide as closely as can be expected with the time as ascertained by other methods),—and a means of ascertaining also the latitude of the place.

699. That the earth is of a spheroidal form, and not a perfect sphere, is proved by the diminishing force of gravity towards the equator, by the diminution of the degree of latitude the nearer the place is to the equator, by analogy from the other planets, as Jupiter and Saturn, by the tendency of rotation to produce such a form, and by the phenomena of precession and nutation, in which we observe effects such as would arise from a protuberance towards the equator.

SECTION III.

The Earth and the other Planets move Round the Sun.

700. (1.) When the sun is observed from day to day throughout the year, and his position in relation to the constellations watched, it is found that every 365 days he makes a complete tour of the heavens; that, setting out from the vicinity of any star, he moves to the east of it, daily increases his distance from it, till he is 180° from it in the opposite quarter of the heavens, then approaches towards it, and returns to the same position near it at the end of one year. This may be ascertained by observing his successive distances from any prominent star that is visible, or by observing from time to time what stars rise just before or set just after him, by which we can ascertain his position among the stars with tolerable exactness. Now this apparent yearly motion of the sun can be perfectly explained on the supposition that the sun is a fixed centre round which the earth moves in the same direction in the same time. This will be understood by reference to Fig. 60. Let A represent the earth, moving in the orbit A B *a b* in the direction indicated by the arrows, the sun being represented in the centre of the figure. It is manifest, that if the earth move from A to B, the sun, seen from A in the position *a s* among the stars, will from B appear at *b s*, and thus must appear to have moved from *a s* to *b s* through the starry heavens. As the earth passes from B eastwards, the sun must appear to pass westwards from *b s;* and when the earth arrives at the opposite part of its orbit, *a b*, on the other side of the sun, the sun must be seen in the opposite quarter of the heavens A S B S, and while the earth moves in her orbit from *a* to *b*, the sun appears to move among the stars from A S to B S.

701. (2.) The theory of the fixity of the sun and annular motion of the earth round that luminary is so much simpler, and avoids so many improbabilities, that it has been adopted as the true one since about the times of Copernicus and Galileo. It seems very unlikely that a large body like the sun should be revolving round one so much smaller, and is quite contrary to what we observe in the other parts of the solar system, as the lesser systems of Jupiter, Saturn, Uranus, and our own earth, with their attendant satellites. This improbability is greatly increased when we consider the number of large planets circulating round the sun as their undoubted centre, at vast distances from him. We cannot realize the idea of so vast a system being dependent upon and revolving round our comparatively puny earth. Also the motions of the planets (particularly their retrograde movements) are infinitely complex and almost unintelligible on the theory of the earth's fixity as the centre of the universe; while all their movements become plain, simple, and uniform on the other theory.

702. (3.) The other planets are known to move round the sun by observing their movements through the starry sphere, the different positions they occupy in respect to the earth and sun at different times, and particularly in the cases of Mercury, Venus, and Mars, by the magnitude and position of the *phases* which they exhibit at different times.

703. (4.) The phenomenon of the aberration of light (653) affords the most convincing proof of the earth's annual motion.

704. (5.) By the laws of mechanics, any force which would impart a motion of rotation to a body free to move, must also impart to it a motion of translation, which could then be stopped only by a force in an opposite direction through its centre of gravity; from which there is necessarily a strong presumption in favour of an outward motion in any body rotating in free space.

PART VI.

THE FIXED STARS.

705. Those stars which preserve the same positions in relation to each other, without material change, are called "fixed stars." Such are the stars in the constellation "Great Bear," which appear to the "oldest inhabitant" to be clustered in the same form in which he saw them in his childhood. It is known from good records that form has not materially altered for hundreds of years. And we have reason to believe that the stars of the leading constellations appear to us now just as they did to the astronomers who flourished long before the Christian era, and who arranged the stars in constellations, and gave them the names they still bear—names derived from the heroes and heroines of antiquity, and which have stamped on the heavens in indelible characters the heroic deeds and elegant fables of ancient times.

706. The fixed stars, however, are not absolutely fixed. Many of them do change their positions in relation to each other. But this change, called their **proper motion**, is very slight; so much so that it must go on for thousands of years before it causes a change in position appreciable by the naked eye. The stars Sirius, Arcturus, and Aldebaran have moved southward, respectively, 37′, 42′, and 33′, since the time of Hipparchus—more than half a degree. The star 61 Cygni has been ascertained to have a proper motion to the extent of 5·3″ yearly, about a degree in 700 years; and some are believed to have a proper motion of so much as 7·7″ annually.

707. It was believed by Sir William Herschel, and

has been confirmed by succeeding astronomers, that there was a tendency to an opening out or spreading of the stars in a particular region of the heavens, such as would be caused by our approach towards that quarter of the heavens, and a crowding together of the stars in the opposite part of the sky, such as would be caused by our receding from these stars. Hence has arisen the bold conjecture, otherwise not improbable, since every analogy is in favour of motions both of rotation and translation in the heavenly bodies, that our sun has a proper motion through space, carrying all the planets, satellites, and comets along with it. It is supposed that this motion is towards the constellation Hercules (to a point in R. A. 261°, N. P. D. 37°); and that it is at the rate of 422,000 miles (or nearly the sun's radius) daily, or 154,185,000 miles in a year. Speculations have even been entered into as to the centre round which our sun moves; one astronomer (Mädler) having conjectured that that remarkable point is the star Alcyone, in the constellation Pleiades; and this is now the general belief of astronomers.

708. All the stars usually seen in the heavens by the naked eye are fixed stars, excepting five, and an occasional comet.—See par. 45. They may be distinguished from the planets and comets by their property of *twinkling*, that is, alternately expanding and contracting their rays. The planets shine with a steady equal light.

709. Until recently very little was known regarding the fixed stars. We could judge of their *relative brightness*, we could ascertain the direction and velocity of their *apparent daily motion round the earth*, and any other motions they exhibit, and we could determine that they are at not less than a certain distance from us. But we did not know their actual magnitude, nor, except in the case of a few, their distance from the earth.

710. In the first place, all attempts to measure the

distance of any of the fixed stars had failed. None of them gave any parallax with the longest known base-line within our reach—the radius of the earth's orbit, 92 millions of miles. In the year 1838, however, the parallax was measured in the case of three of them. The parallax of α Centauri was ascertained by Professor Henderson, at the Royal Observatory of the Cape of Good Hope, to be 0·9128″ or about $\frac{1}{1}\frac{9}{0}$ths of a second; that of 61 Cygni, by Professor Bessel of Königsberg, to be 0·3483″; and that of α Lyræ, by Otto Struve, to be 0·25″. The major diameter of the earth's orbit being about 185,000,000 miles, a parallax of *one second* will give a distance of 20,000,000,000,000 (twenty billion) miles, which is, therefore, the probable distance of α Centauri from the sun—a distance so great that light, travelling at the rate of 185,000 miles per second, would require three and a half years to traverse it. The distance of the star 61 Cygni, its parallax being only $\frac{1}{3}$ of a second, will be *thrice* this number; and of α Lyræ, *four* times twenty billions. The distance of about twenty fixed stars (including Sirius, Arcturus, Polaris, and Capella) is now approximately determined.

711. We have no certain knowledge of their **size**, for, even when viewed through the telescope, they present no disc or surface whose breadth can be measured. Even by the aid of this instrument they appear, as to the naked eye, brilliant shining points, only more bright and luminous.

712. The different magnitudes which the fixed stars present to us may arise from their different distances, different degrees of brightness, or from actual differences in magnitude: being, in most cases, ignorant of the two former, we have no sure data for judging of the latter. For the present we must be satisfied with approximate results. The star α Centauri is ascertained to be three times brighter than our sun. "Sirius is more than four times brighter than α Centauri, but yet shows an annual change of position among the stars of not more than one-fourth of that star's. It is therefore supposed to be four times farther away

from us than α Centauri; and, did it emit no greater amount of light, would appear to shine with but one-sixteenth of that star's lustre. But as in reality, it is four times as bright, the real amount of light it emits must exceed that of α Centauri no less than sixty-four times, and that of our sun no less than 192 times. So that, judged from this indication alone, the diameter of Sirius may be held to exceed that of our sun in the proportion of about 14 to 1—an estimate which assigns to Sirius a diameter of nearly 12,000,000 miles, and a volume of 2688 times as large as the sun's."—*Proctor.*

713. It has been calculated that if any of the more remote stars which the telescope brings into view be equally bright with those near us, the light of such stars must have occupied more than 2000 years in coming to us; and that the rays which render them visible to us do not indicate their existence *now*, but their existence 2000 years ago.

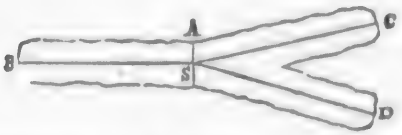
714. The fixed stars are supposed to be suns, having planets revolving round them, which they preserve in their orbits, supply with light and heat, and thus render fit to be places of abode for living beings.

715. It is considered that they are independent systems, not subservient to our universe, much less to our earth; because they shine from their own light, because, from their great distance, their influence on the solar system must be very slight, and because it is improbable that bodies of the magnitude which their distance shows the fixed stars to possess, are subsidiary to our comparatively small system. That the stars shine by their own inherent light, not by reflecting the sun's rays, is shown by their enormous distance from that luminary.

716. "The stars of our firmament, instead of being scattered in all directions indifferently through space, form a stratum, of which its thickness is small, in comparison with its length and breadth; and in which the earth occupies a place somewhere about the middle of its thickness, and near the point where it subdivides into two principal laminæ inclined at a small angle to each other. For it is certain that, to an eye so situated, the apparent density of the stars, supposing them pretty equally scattered through the space they occupy, would be least in a direction of the visual ray (as S A), perpendicular to the lamina, and greatest in that of its breadth, as S B, S C, S D; increasing rapidly in passing from one to the other direction, just as we see a slight haze in the atmosphere thickening into a decided fog-bank near the horizon, by the rapid increase of the mere length

of the visual ray. Such is the view of the construction of the starry firmament taken by Sir William Herschel, whose powerful telescopes first effected a complete analysis of this wonderful

Fig. 61.



zone, and demonstrated the fact of its entirely consisting of stars. So crowded are they in some parts of it that, by counting the stars in a single field of his telescope, he was led to conclude that 50,000 had passed under his review in a zone two degrees in breadth, during a single hour's observation. In that part of the Milky Way which is situated in 10h. 30m. R. A., and between the 147th and 150th degree of N. P. D., upwards of 5000 stars have been reckoned to exist in a square degree. The immense distances at which the remoter regions must be situated will sufficiently account for the vast predominance of small magnitudes which are observed in it."—*Sir John Herschel.*

717. The fixed stars are arranged according to four different principles:—1. According to their brightness. 2. In constellations.—3. According to their situation in the heavens.—4. According to their kind, so far as that can be discovered.

1. Divisions of the Stars according to their Brightness.

718. The fixed stars are divided, according to their brightness, into classes termed *magnitudes*. The brightest are said to be of the *first magnitude*, the next in point of brightness of the *second magnitude*, and so on, down to the sixth magnitude, which are the faintest discernible by the naked eye. With powerful telescopes the range is continued down to the sixteenth magnitude. There are about 20 stars reckoned of the first magnitude. Of these 11 are visible in Great Britain. **Sirius,**

the dog-star, is the brightest of the stars of the first magnitude. There are about 65 of the second magnitude, 190 of the third magnitude, and, in all, nearly 5000 have been registered, including the sixth magnitude. It is only at the equator, however, that so large a number can be seen, for there only the spectator has the opportunity of surveying the whole heaven without altering his position. At Alexandria the number of stars visible to the naked eye is only 4638; at Paris, 4146; and at Berlin, 3206. The whole number of stars already registered, including those of the seventh magnitude, is about 18,000, but astronomers assert that the total number of stars visible through the best telescopes, down to those of the fourteenth magnitude, exceeds 20,000,000; while, by including those of the fifteenth and sixteenth magnitude, the number may possibly amount to 500,000,000,000, or half a million of millions!

719. Seldom above 1000 are visible at a time to the naked eye. Those of the fifth and sixth magnitudes may, on a clear night, be discerned without the aid of a telescope. The **Milky Way** is composed of innumerable stars, whose average brightness is about the eleventh magnitude, and whose joint light is therefore separated only by very powerful telescopes.

720. Every increase in the powers of the telescope brings new stars into view; and as their distances are so great, it is possible that there may be myriads of stars so remote from our system that their light has never reached the earth, though they may have been created at the same period as our system; while others, whose light still reaches us, may have been long since extinguished. There is no reason to suppose that the boundaries of the sidereal system are within reach of even our most powerful telescopes. The most remote of the stars which the best telescopes bring into view may owe their apparent minuteness, not to inferior magnitude, but to immense distance; and, perhaps, an observer at the furthest of these would find the same appearance as we do. star beyond star in countless myriads and at inconceivable distances, of which it baffles the mind to form any adequate conception.

2. Arrangement of Fixed Stars in Constellations. 3. According to their Situation in the Heavens.

These two methods have been already described in our account of the sphere of the heavens, and need not be again discussed here.

4. Arrangement of the Stars according to other Differences than their apparent Brightness or Situation.

721. Considered with respect to other differences than their situation or brightness, the fixed stars may be divided into six kinds:—1. Ordinary fixed stars; 2. Temporary stars; 3. Variable stars; 4. Binary stars; 5. Nebulæ; 6. Clusters of stars.

1. Ordinary Fixed Stars.

722. These are the stars which, either to the eye or in the telescope, do not present any peculiar phenomenon, such as variation in lustre, motion, nebulous appearance, or are not aggregated with any other stars in a distinctly separate cluster. This is the case with many of the fixed stars.

2. Temporary Stars.

723. These are stars which have appeared for a limited time, and then disappeared. Many stars, given in old catalogues, are not to be seen now; and on several occasions, in various parts of the heavens, new stars have suddenly come into view, and disappeared at longer or shorter intervals, shining with various degrees of brilliancy during their short career. It is said that it was the sudden appearance of a new and bright star in the heavens, about 125 B.C., which led the illustrious ancient astronomer **Hipparchus** to the idea of making

a catalogue of the stars, which he did. Some of these, which have appeared at different periods, are conjectured to be periodical in their visitations, especially the stars of 945, 1264, and 1572, which appeared in the same region of the heavens, and have been thought to be *the same star* with a period of about 300 years. The star of 1572 appeared so suddenly that Tycho Brahe saw several people looking at it, attracted by its brilliancy, where he was certain it was not prominent half-an-hour previously.

3. Variable Stars.

724. The variable stars present the singular phenomenon of a change in their brightness; they undergo a regular alternate increase and diminution in their lustre; and several altogether disappear for a time. They are sometimes termed *periodical*.

725. The second star, β, in the constellation **Perseus**, is a variable star, the phenomena of which are visible to the naked eye. It is just on the margin of the Milky Way, on the side of it farthest from the north pole-star, and about the same distance from that star as Vega. It is in R. A. 45°, D. N. 40°. It may be found by drawing a line from the pole-star in the direction of the letters *Per*, in Fig. 1, page 13; and is shown in Fig. 2, page 15, above the word "Perseus." It is called **Algol**, and usually appears as a star of the second magnitude. It remains so for $2^{d}\cdot 14^{h}$, when it suddenly begins to diminish in brightness, and in about $3\frac{1}{2}$ hours dwindles to a star of the fourth magnitude. It then begins again to increase and in $3\frac{1}{2}$ hours returns to its usual brilliancy, going through all its changes in $2^{d}\cdot 20^{h}\cdot 48^{m}$. The star η of the southern constellation Argus has exhibited very remarkable changes in lustre, from the fourth to the second magnitude, then to the fourth, then to the second again, and during the present century to the first and second magnitudes alternately.

726. This singular and regular change in the brightness of Algol, is attributed to the revolution of some body round it, sufficiently large to cut off a portion of its light when interposed between the earth and the

star, though not of sufficient magnitude to eclipse the star altogether: in other cases it may be caused by rotation, the body having a dark and bright side—or by revolution in an elliptic orbit with the longer axis nearly in a line with our position.

727. The following are some of the leading variable stars visible in Great Britain. β (beta) of Perseus; δ (delta) of Cepheus; β (beta) of Lyra, a little south from Vega; α (alpha) of Hercules; o (omicron) of Cetus. These have periods varying from about 3 to 331 days, that of omicron of Cetus. The latter is one of those variable stars which disappear altogether for a time. It is called **Mira**, is a star of the second magnitude when at its brightest, in R. A. about 32° or 2^h. 10^m., and D. S. between 3° and 4°. It is nearly due south of the leading stars in **Aries**: and is shown in Fig. 11, page 32. It appears about 12 times every 11 years, and remains tolerably bright for upwards of a fortnight.

4. Binary Stars.

728. **Binary** stars are those stars which, on examination with the aid of a powerful telescope, and observation for a considerable time, are found to consist of two stars nearly equal in apparent magnitude, and having a revolution round each other,—"Sidereal systems, composed of two stars revolving about each other in regular orbits."

729. This great discovery was made by **Sir William Herschel**, towards the close of the last century. It was first publicly announced in papers read to the Royal Society of London in 1803 and 1804.

730. About 6000 binary stars have been discovered, and the periods of revolution of 700 of them have been determined. In **Castor**, which is a binary star, the revolution is completed in 252 years. In a binary star in Corona Borealis the orbit is completed in 43 years; and therefore a complete period has in this instance been gone through since the discovery by Sir W. Herschel. The following are some of the most remarkable of the binary stars: γ (gamma) of the constellation

Virgo (182 years); η (eta) of Cassiopeia (181 years); α Centauri (75 years); ξ Ursæ Majoris (63 years); γ (gamma) of Leo (1200 years); δ (delta) of Cygnus (178 years).

731. The binary stars are often coloured, each being of a different hue; and they usually exhibit those tints which are called complementary, as blue and yellow—red and green. Triple, and even quadruple stars have been discovered, in which three or four stars are grouped together, forming one connected system.

732. The phenomena of periodical and binary stars seem to indicate that among the fixed stars there are the same general laws which prevail in our solar system; for wherever we observe motion in an orbit, there we must infer the existence of some force analogous to that of universal gravitation. "No doubt," says Sir John Herschel, referring to the double star γ Virginis, "can remain as to the prevalence in this remote system of the Newtonian law of gravitation."

733. Stars of nearly equal magnitude, and placed close to each other, but in which no revolution has yet been detected, are termed **double stars.** Of these, there is a very great number.

5. Nebulæ.

734. Nebulæ are faintly luminous stars, different from either of the preceding varieties. The leading kinds are two:—(1.) Those which are resolved by powerful telescopes into a collection, or *globular cluster*, of separate stars, densely crowded into one luminous mass in the centre, but becoming scattered and separate towards the border. These are regarded as systems of suns,—as a whole world of stars, separate from other systems; the individuals of which are probably suns, at great distances from each other.

735. (2.) Another kind of nebulæ, to which the term

nebula is most usually applied, is that in which the star appears a thin cloudy mass, of that fleecy appearance observed in the tail of a comet. The latter nebulæ, it was at one time imagined, may be gaseous matter in the process of formation into suns with their attendant planets: but recent examination of nebulæ presenting this character by more powerful telescopes, such as that of **Lord Rosse**, having entirely, or partly, resolved many of such nebulæ into numbers of separate stars, it has been presumed that they might all be so resolved if we had telescopes of sufficient power. The nebulous theory of the formation of the sun, planets, and other stars and systems, has thus lost the support it derived from the apparently irresolvable nebulæ. But it still remains as an explanation of a possible mode of formation of the heavenly bodies, sanctioned formerly by the great names of **Sir W. Herschel** and **La Place.**

736. The nebulæ exhibit every variety of form, from the circular to that of an elongated ellipse; such as the nebulæ in the girdle of Andromeda, which is visible to the naked eye. Some are termed *annular*, from their ring-like form; and others *planetary*, from their resemblance to planets in presenting discs; others are termed *nebulous stars*, appearing as bright stars surrounded by a faint luminosity; and Lord Rosse's telescope has revealed another class of a very remarkable character, termed *spiral nebulæ*, from the spiral coils of luminous matter which they exhibit. The remarkable objects called the Magellanic Clouds, near the southern pole of the heavens, are two rounded luminous spots, like a portion of the Milky Way; and are found to be resolved by the telescope into separate stars, globular clusters, and almost every variety of nebulæ. Their light is not great, and the lesser disappears in bright moonlight.

6. Clusters of Stars.

737. Where there is a number of stars gathered together, apart from the others, and forming in a manner an isolated group, they are termed a *cluster*, and are considered to belong to some system separate from the general body of the stars. The **Milky Way**, the

Pleiades, Coma Berenices, the bright spot in Cancer called **Præsepe** or the Beehive, are examples of these clusters.

738. It thus appears that there are many descriptions of fixed stars, as they are called, and that no stars are truly fixed, but that movements and changes are going on amongst them, which in time must greatly alter the appearance of the heavens; that the universe has no bounds that we can even fancy; and that wherever we know it, it is full of matter and of motion of every form and variety. There is no point in space that has not some body in it, or some influence passing through it. There are no voids—no objects fixed and unchanging. Life, force, activity, and endless change pervade the boundless realms of creation.

PART VII.

SKETCH OF THE HISTORY OF ASTRONOMY.

739. As the heavenly bodies are everywhere conspicuous, and naturally attract the attention;—as many of their relative changes of position are obvious, and must have been observed by even the rudest tribes; and as the coincidence of these changes with important terrestrial phenomena could not escape observation; Astronomy has been cultivated from the earliest ages, and is by far the oldest of the sciences.

740. The origin of this science cannot be distinctly traced to any one country or people. The earliest authentic records show that it was cultivated simultaneously, and with considerable success, by the four great nations of remote antiquity, the **Chaldeans, Egyptians, Indians,** and **Chinese.** The Egyptians and Chaldeans had divided the year into 365 days, observed the direct and retrograde motions of the planets, and that they were sometimes stationary, that the ecliptic was inclined to the equinoctial, and had the zodiac divided into twelve constellations;* besides many other important astronomical phenomena. The Chaldeans are said to have been the first who divided the day into twelve hours; and the Egyptians first used the period of seven days—the week.

741. From **Egypt,** which has been justly termed the "cradle of the arts and sciences," and from **Chaldea,**

* Some of the ancient Oriental nations (Indians and Chinese) divided the zodiac into 27 portions corresponding to the moon's daily progress, called the *Houses* or *Mansions of the Moon.*

a knowledge of astronomy passed into **Greece**. Among the philosophers of that country, and of the famous school of **Alexandria**, founded in **Egypt** by **Ptolemy**, after the death of **Alexander the Great**, Astronomy was cultivated with much zeal, and enriched by numbers of new observations, and important corrections of former observations.

742. **Thales** is the first Grecian on record who seems to have given a stimulus to astronomy. He is said to have predicted an eclipse of the sun, to have understood the nature of eclipses, to have discovered the obliquity of the ecliptic; and to have pointed out the Little Bear by which to steer as a guide to the north, instead of the Great Bear. He lived about 600 B.C. He is said to have been of *Phœnician* extraction. The Phœnicians steered by the Little Bear.

743. The present view of the solar system was first promulgated by **Pythagoras**, a famous Grecian philosopher, who flourished about 500 years before the commencement of the Christian era; and taught by his disciple **Philolaus**. He supposed the sun to be in the centre, and the earth and planets to revolve round it; and was persecuted for holding this opinion.

744. But this opinion was not generally entertained. It was confined to *some* of the learned, and was not confidently taught or firmly believed by them. The majority of the philosophers of those days, as well as the people, entertained the popular notion that the sun, moon, planets, and stars, revolve daily round the earth, supposed to be fixed. Though it is conjectured that the true system of the universe was known to some before **Pythagoras**, as **Anaximander**, it has been always termed the **Pythagorean System**.

745. The progress of discovery and improvement in Astronomy, in ancient times, was greatly retarded by assumed fancies regarding the perfection and immutability of the heavenly bodies; the gross and corrupt nature of the earth, and the entirely opposite natures of

the earth and the heavenly bodies; the perfect nature of the circle; the notion that the celestial bodies must move in circles, and that their motions must be uniform; and many other dogmas which had the sanction of the great name of **Aristotle.**

746. **Hipparchus,** who has usually been regarded as the "Father of Astronomy," flourished about 140 B.C. He determined with greater accuracy the length of the year; discovered the inequality in the rate of the sun's motion, which he explained by supposing the earth not in the centre of the sun's orbit; observed the inequality in the length of the solar day; discovered the precession of the equinoxes;* drew up a catalogue of the fixed stars, with their precise positions, and determined the positions of places on the earth's surface by their latitudes and longitudes. He is said to have been the inventor of spherical trigonometry.

747. **Ptolemy** of Alexandria, who flourished about 130 years after the commencement of the Christian era, being born in the year 69, is the next astronomer of note. He was the author of a work on astronomy, called "The Great System," which is still preserved, being known by the name of *Almagest*, which it received from the **Arabians,** in which the whole astronomical knowledge of the times is recorded.

748. **Ptolemy** upheld the popular system that the earth is a fixed centre, round which all the heavenly bodies revolve daily. He placed the stars, sun, moon, and planets in the following order of distance from the earth:—viz., Moon, Mercury, Venus, Sun, Mars, Jupiter, Saturn, and, lastly, the sphere of the fixed stars. This was the **Ptolemaic System,** which so long held possession of public opinion.

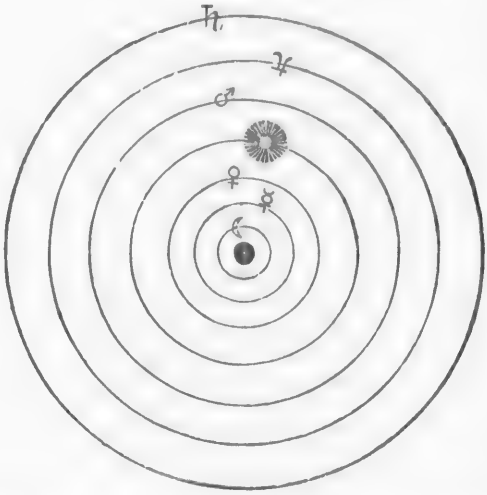
---

* But the precession of the equinoxes must have been known to the architect of the Great Pyramid, erected B.C. 2170. (See "Facts and Dates," p. 131.)

Ptolemy argued that if the earth moved round the sun, the poles of the heavens would not always remain the same, that the fixed stars would not preserve the same figures and relative distances,* that the earth, by the greatness of its mass, would move faster than the loose bodies on its surface, so that they

Ptolemaic System.

Fig. 62.



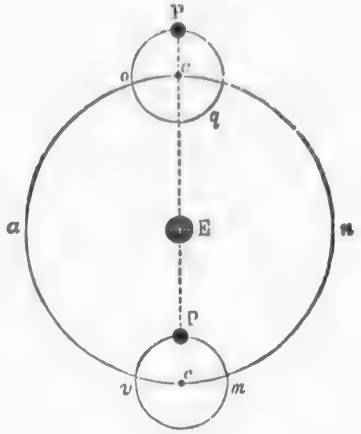
would be left behind, and that the earth would soon move out of the heavens. He objected to the earth's rotatory motion, that if such were the case, clouds, birds, and bodies floating in the atmosphere would be left behind.

749. The apparently irregular and retrograde movements of the planets were explained by the theory of **Epicycles**:—namely, that the heavenly bodies revolve in small circles, the centres of which move in regular

* These objections had been removed by the suggestions of previous astronomers, that the earth's orbit might perhaps be a mere point in comparison with the distance of the stars.

orbits round the earth. Thus, let E, in Fig. 63, be the earth, and P any planet revolving round the earth. It is supposed to revolve in a small circle, P *o q*, round a centre *c*, which again revolves in the circle *a m n o* round the centre E, the earth. The small circle P *o q*,

Fig. 63.



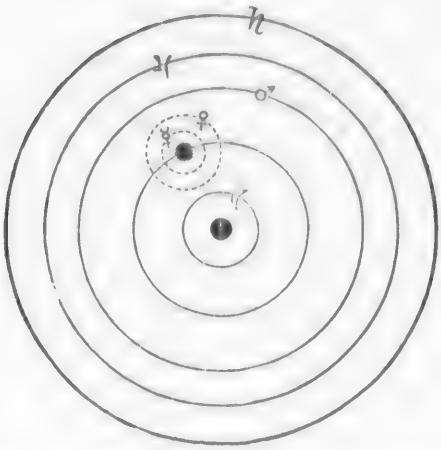
in which the planet revolves, is called an *epicyle*, and the large circle round which it turns the *deferent*. This theory had been devised by **Apollonius** to explain the retrograde movements of the planets.

750. Ptolemy also entertained the *eccentric hypothesis*, namely, that the earth was not exactly the centre of the orbits of the sun and planets, by which the apparent inequality in the rate of the sun's motion was explained. He considered the earth to be spherical, and a mere point in comparison with the distance of the fixed stars.

751. It has been said that the ancient Egyptians at one period held the opinion that Venus and Mercury had the sun, and not the earth, for the centre round which they revolve, to explain the constant vicinity of these planets to the sun. This was the

Egyptian System.

Fig. 64.



752. After the time of **Ptolemy**, Astronomy made little progress for more than a thousand years. It was cultivated by the **Arabs**, who made some additions and corrections, and some improvements in trigonometry; and through whose invasion of Spain it was introduced into Europe in the ..inth century.

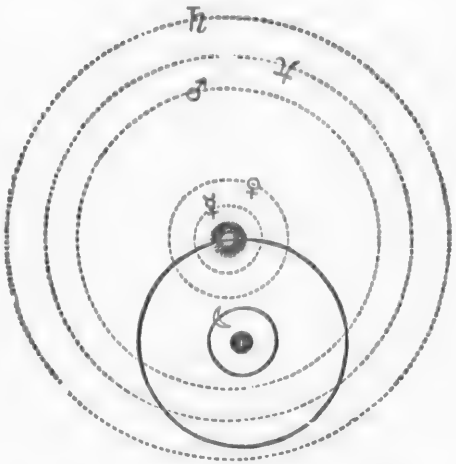
753. In Europe, Astronomy made little progress till the restoration of the true system of the planets by **Copernicus**. This distinguished man was born at Thorn in Prussia in 1473. He was professor of mathematics at Rome, but spent his latter days in his own country. In meditating upon the phenomena of Astronomy, he found that the Ptolemaic system did not afford an adequate explanation of them, and that the Pythagorean system accounted satisfactorily for all the changes and motions. He accordingly adopted it: and his views were published in a work called **Astronomia Instaurata**, which was published only a few days

before his death, which took place in 1543. His system, called the **Copernican System**, has now been fully established.

754. The next astronomer of note was **Tycho Brahe**, a Dane, born in 1546. He made many important corrections of previous observations, drew up a catalogue of the stars, discovered the refraction by the air, and many important points in the motions of the moon, and ascertained the comets not to be atmospheric phenomena, by showing their great distance, etc. He devised a planetary system, in which the earth was placed in the centre, and the sun and moon were conjectured to have the earth for their centre of motion, while all the planets were supposed to have the sun for their centre. This, which has been called the

Tychonic System,

Fig. 65



was devised to accommodate better to astronomical phe-

nomena the idea of the earth being the centre of the whole, to which **Tycho Brahe** adhered.

755. **Kepler** was born in Würtemburg in 1571. He was a pupil of **Tycho Brahe**, on whose observations his important discoveries were founded. He hinted at some such power as gravitation, and applied it to the phenomena of the earth and moon and the tides. He developed the three laws stated in par. 454,—the basis of the science of Astronomy.

756. The celebrated **Galileo** made great contributions to Astronomy. He was born at Florence in 1564. He invented the pendulum, discovered the spots on the sun and its rotation on its axis, ascertained that Venus had phases like the moon, as Copernicus had predicted; that the moon's surface was not smooth and rounded, but rough and irregular, like the earth's; that the planets expand into a broad opaque disc when viewed through the telescope, while the fixed stars still appear as mere shining points; and discovered the satellites of Jupiter. He was a leading advocate and promoter of the Copernican system, for which he suffered much persecution; and died in 1642, having enriched Astronomy and Mechanical Philosophy with many valuable discoveries. His great work, "Dialogues on the Ptolemaic and Copernican Systems," was published in 1632.

757. **Hevelius, Huygheus,** and **Cassini** in the early part and middle, and **Flamsteed** towards the close of the 17th century, lent considerable assistance to the advancement of astronomical science. Flamsteed drew up a catalogue of the stars. **Hooke,** about the middle of this century, gave hints of the theory of universal gravitation. Towards the close of the century **Roemer** discovered the progressive motion of light: and Picard, the Cassinis, and others, made approximations towards ascertaining the true figure of the earth by measuring the length of the degree at different latitudes.

758. **Sir Isaac Newton,** the founder of the **Science** of Astronomy, was born in England in 1642. He pub-

lished in 1686 his immortal work, in which he developed the great laws of universal gravitation, and applied them to the explanation of the motions of the heavenly bodies. It was titled *Philosophiæ Naturalis Principia Mathematica*. Besides establishing Astronomy on scientific principles, he also made valuable additions to Optics and Mathematics. He died in the year 1727.

759. Another distinguished English astronomer, **Dr Edmund Halley**, was born in 1656 and died in 1742. He suggested the transit of Venus over the sun's disc as a means of finding the sun's parallax; and calculated the elements and predicted the return of the comet which now bears his name. He made other valuable contributions to Astronomy.

760. **Dr Bradley**, born in 1692, made the two capital discoveries of the aberration of light and nutation of the earth's axis; besides many other improvements in astronomical science. **Clairaut, D'Alembert, Euler, Simpson, La Place** (to whom is due the credit of completing the work that Newton had begun), **La Grange**, and **La Lande**, made many improvements and extensions in astronomical science. By these, particularly La Place and La Grange, various irregularities in the motions of the planetary system were reconciled with the theory of universal gravitation, and others previously unknown were deduced from it; and the mutual correction of the various disturbances, so as to preserve the ultimate stability of the system, was proved—one of the greatest steps Astronomy made after the development of Newton's grand discoveries.

761. **Sir William Herschel**, towards the close of the last century, discovered **Uranus** and his satellites, the two inner satellites of Saturn, and ascertained its ring to be double. He also discovered the phenomena of the binary stars, and extended greatly our knowledge of the fixed stars.

762. During the present century, Astronomy has

been cultivated with great success, and many important additions have been made to our astronomical knowledge. The **Asteroids** have been discovered, 4 in the early part of the century, and upwards of 120 recently; **Neptune** has been added to the list of known planets, by **Leverrier** and **Adams**, in a manner that has astonished the world by the wonderful accuracy it has proved in astronomical observations and calculations. Numbers of comets have been observed, and their periodic times calculated, and the phenomena of one of these has tended to confirm the idea of the existence of a universal **Ether** diffused throughout space. A second return of the comet of **Halley** in 1835—the first comet whose return was predicted—has confirmed his computations, and those of his successors who had calculated the operation of disturbing influences on its motions. The meteors that flash across the sky are beginning to take their place in the planetary system. The fixed stars, which so long resisted all attempts to find their parallax, have at last yielded to the perseverance of **Henderson, Bessel, Struve**, and others, and parallaxes have been found for many of these remote suns; so that we can now assign a definite distance for them, which will be made the basis of further discoveries. Governments, associations, and individuals have alike conspired to promote astronomical research. **Sir John Herschel** visited and resided long in the south of Africa, for the purpose of exploring the southern skies; and extended immensely our knowledge of these interesting regions of the heavens. The famous telescope of **Lord Rosse** has made its wonderful revelations. New catalogues of the stars have been prepared, and observatories founded. By these means a mass of observations has been accumulated, which must extend our knowledge of the most remote parts of creation, and pave the way for new inductions and discoveries. Among very recent discoveries there are two which rival the most brilliant of any

former time, viz.:—*first*, the discovery of the earth's true distance from the sun; and, *second*, the splendid invention of spectrum analysis, by which we have come to know that the materials of which the sun, planets, and stars are composed do not differ in any respect from those which prevail in the world which we inhabit.

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